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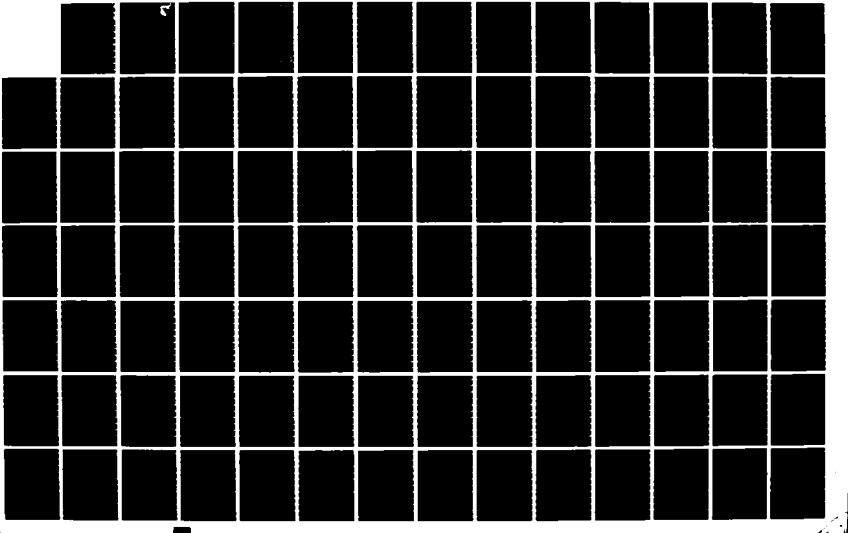

AAMRL-TR-86-007

REGISTER OF RESEARCH IN PROGRESS ON MENTAL WORKLOAD (U)

THOMAS R. METZLER
ARMSTRONG AEROSPACE MEDICAL RESEARCH LABORATORY

FEBRUARY 1986

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ARMSTRONG AEROSPACE MEDICAL RESEARCH LABORATORY
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AAMRL-TR-86-007

This report has been reviewed by the Office of Public Affairs (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

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FOR THE COMMANDER

CHARLES BATES, JR.
Director, Human Engineering Division
Armstrong Aerospace Medical Research Laboratory

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This report documents current research on operator workload. The register was compiled from responses to a questionnaire data form sent to 76 scientists who are active in basic and applied workload research. The six sections of the register include name and key term indexes, current project descriptions, listings of workload laboratories and potential sources of research support, and a bibliography of significant publications in the area.

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SUMMARY

This report documents current research on operator workload. The register was compiled from responses to a questionnaire data form sent to scientists known to be engaged in workload research. This is the second update of the register which is intended as a communication medium for people actively engaged in workload research.

PREFACE

The compilation of this document was accomplished by the author in fulfillment of Air Force Reserve active duty. The work was performed for the Workload and Ergonomics Branch, Human Engineering Division, Armstrong Aerospace Medical Research Laboratory (AAMRL/HEG). The effort was accomplished in support of AFSC Project 7184, Man-Machine Integration Technology, for the Air Force.

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Section 1

INTRODUCTION

This volume is the third in a periodic series of reports of current research on operator workload. As in any highly active area of scientific investigation, progress toward the understanding of mental workload is impeded by a less than adequate system of professional communication. Lengthy publication delays, the wide variety of journals and technical report sources in which workload research appears, and the sheer volume of data being produced substantially detract from the crucial flow of information among scientists and users of workload research. These problems are ultimately reflected in a tendency for needless duplication of effort and a reduction in the efficiency with which research findings are translated into equipment design and training solutions.

The Register of Research in Progress on Mental Workload was conceived as one means by which communication and cooperation among researchers could be improved. Essentially, the register is intended to act as a directory to workload scientists and their projects. For a third year, data forms were sent to individuals selected on the basis of known previous activity in the area. Seventy-six persons currently engaged in workload research contributed responses. The information provided by the researchers was compiled along with the data obtained in the 1980 and 1982 editions to produce the six sections comprising the 1985 register.

The first two sections provide a name index and a list of key terms which may be used to facilitate access to more specific information on individual research efforts. The third section contains data on each researcher's affiliation, mailing address, and telephone number. In addition, each entry is accompanied by current project descriptions provided by the respondent. The fourth section is a listing of laboratories engaged in workload research. The final two sections contain general information deemed to be of possible use to both present and future researchers in the area. The fifth section lists organizations which, according to the respondents, have interests in workload research and may be sources of funding for such efforts. The sixth section contains responses to a request to list those publications, reports, and books which have made the most significant contributions to the understanding of mental workload.

Present plans call for the register to be updated and published on a biennial basis. Comments on the format of the register, potential improvements, and suggestions concerning the inclusion of significant research efforts not represented in this edition are welcomed. Please address any correspondence to:

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Section 3

KEY TERM INDEX

A fixed list of key terms was provided on the data form. Respondents are listed under all key terms which they indicated as being descriptive of their research interests.

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Lindholm, Ernest
Linton, Paul M.
Mulder, G.
Pflendler, Claudius
Pianka, Michael
Sanders, Mark S.
Schiflett, Sam G.
Schubert, Klaus-Peter
Sheridan, Thomas B.
Siegel, Arthur I.

COMMAND CONTROL AND COMMUNICATIONS SYSTEMS

Alluisi, Earl A.
Beattie, J. David
Butterbaugh, Larry C.
Christensen, Julien M.
Crabtree Mark S.
Ephrath, Arye R.
Gabriel, Richard F.
Gevins, Alan S.
Goldbeck, Robert A.
Gopher, Daniel
Hopkin, V. David
Johnson, Edgar M.
Lane, Norman E.
Levine, Jerrold M.
Linton, Paul M.
O'Donnell, Robert D.
Parks, Donald L.
Rohmert, Walter
Schiflett, Sam
Sheridan, Thomas B.
Shingledecker, Clark A.

INDUSTRIAL SYSTEMS

Beattie, J. David
Borg, Gunnar
Brown, Ivan
Christensen, Julien M.
Gabriel, Richard F.
Gomer, Frank E.
Gopher, Daniel
Hopkin, V. David
Moray, Neville P.
North, Robert A.
Price, Dennis L.
Rasmussen, Jens
Rohmert, Walter
Sanders, Andries F.
Schroiff, Hans W.
Siegel, Arthur I.

WEAPONS SYSTEMS

Brictson, Clyde A.
Butterbaugh, Larry C.
Christensen, Julien M.
Crabtree, Mark S.
Donnell, Michael L.
Edwards, Richard E.
Gabriel, Richard F.
Geiselhart, Richard
Gopher, Daniel
Hartman, Bryce O.
Jahns, Dieter W.
Jex, Henry R.
Lane, Norman E.
Lindholm, Ernest
Linton, Paul M.
North, Robert A.
O'Donnell, Robert D.
Parks, Donald L.
Price, Dennis L.
Qualy, Judi
Schiflett, Sam G.

Section 4

CURRENT PROJECTS

This section contains an alphabetically arranged list of researchers. Each entry includes the researcher's primary organizational affiliation, address, and telephone number, and is accompanied by brief descriptions of one or more current mental workload research activities of the respondent.

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STRESS AND PERFORMANCE IN THE FLYING TRAINING ENVIRONMENT

The objective is to investigate stress in the flying training environment with particular interest directed to stress of simulated flight and subsequent stress of airborne events. Experiments have been planned which (1) allow for quantification of stress experienced in various modes and phases of surface attack training, (2) help determine the interaction of instructor techniques and student stress, and (3) provide a clearer picture of the relationship between stress, learning, and performance in surface attack training.

Three studies will examine (1) physiological indices of stress in A-10 surface attack training, (2) the effect of IP teaching style on student stress, and (3) the effect of combat experience on stress response to simulated A-10 scenarios.

STRESS UTILIZATION/REDUCTION IN FLYING TRAINING

Previous research established the utility of catecholamine excretion as a metric to assess in pilot training. The objective of the present work unit is to determine patterns of stress response in pilots exposed to varying levels of workload/stress in both aircraft and simulated flight scenarios.

Four experiments will be conducted, each of which will assess patterns of stress response as indicated by a selected set of hormones, neurotransmitters, and their metabolites. Urinalysis will be employed. These experiments address (1) stress response of pilots in simulated high threat environments, (2) relationship of psychophysiological and biochemical stress responses, (3) biochemical response profiles to different stressors, and (4) stress in flight line emergencies.

ASSESSMENT OF WORKLOAD AND PREDICTION OF PERFORMANCE BY COMBINED TECHNIQUES

The objective is to develop and implement combined behavioral and psychophysiological techniques for measuring pilot attention and task load during flight simulation. Ultimately, these combined techniques will be used to optimally structure flight simulation training programs and equipment.

A series of laboratory studies will be conducted in order to effectively develop and refine the combined psychophysiological and behavioral measures. These studies will use a simplified flight simulation type behavioral task with task difficulty varying as a function of primary and secondary task difficulty.

A series of related flight simulation studies at AFHRL will also be conducted in order to transfer the laboratory findings to the flight simulation environment.

AIRCREW PERFORMANCE ASSESSMENT SYSTEM FOR THE C-5 SIMULATOR

The objective is to develop and implement an aircrew performance assessment system for the C-5 flight simulator. The performance measurement system shall provide a means by which valid, reliable, objective/quantitative mission performance data may be obtained for C-5 aircrew members. These performance data shall be obtained for all mission essential/critical performance items. The system, as specified, shall constitute a feasibility demonstration or experimental prototype model. As such, it shall provide a means for exploring alternative performance measurement strategies and determining the relationship between measured performance in the simulator and the aircraft.

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SUBJECTIVE ASPECTS OF PHYSICAL AND MENTAL LOAD

During the past 20 years, we have been carrying out studies on various subjective aspects of workload. Most of the studies have concerned performance of, and perceptual responses to, heavy physical work, although subjective effort and difficulty perceived during mental tasks have also been dealt with. We have been using three different kinds of stress indicators of "effort variables": To arrive at a full understanding of man at work, we must study subjectively perceived differences not only over the whole range of working conditions, but also in relation to preferred intensities of effort, adaptation levels, stress conditions, etc., and observe how subjective changes at these levels are related to performance, physiological indicators, and measurements of working capacity (Borg, 1971).

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METHODS TO ASSESS PILOT WORKLOAD AND OTHER TEMPORAL INDICATORS OF PILOT PERFORMANCE EFFECTIVENESS

A systematic approach to define, measure, and describe how certain pilot-related variables influence carrier landing performance during sustained operations is briefly outlined. Previous exploratory research on the interrelations between psychophysiological variables, pilot experience, and performance is described. Pilot work activity, mood, and sleep are identified as indicators of a pilot's temporal state of readiness. A field study design and techniques to measure and describe temporal readiness during prolonged flight operations are provided to demonstrate the methodology in an operational environment. Potential applications of the research are discussed along with the future role of temporal, psychological, and other moderator variables in estimating pilot flight status.

AIRCREW PERFORMANCE RESEARCH OPPORTUNITIES USING THE AIR COMBAT MANEUVERING RANGE (ACMR)

Three years of aircrew performance measurement related to air combat effectiveness using the Navy's Air Combat Maneuvering Range (ACMR) are presented as evidence for ACMR's research potential. Performance assessment methods used to evaluate pilot proficiency are described. The aircrew assessment methods have been used to identify squadron performance differences, evaluate competitive exercises, and provide diagnostic training feedback to operational users. The use of continuously recorded quantitative measures from systems such as ACMR should stimulate more aircrew performance field research ideas. The availability of objective performance criteria promises to be of substantial benefit to both the operational user and the research community in such areas as pilot selection and training, fleet combat readiness, and pilot workload and stress.

PREDICTION OF PILOT PERFORMANCE: BIOCHEMICAL AND SLEEP-MOOD CORRELATES UNDER HIGH WORKLOAD CONDITIONS

A preliminary study of pilot performance, blood chemistry, and sleep/mood patterns during prolonged periods of carrier operations indicated that changes in pilot metabolism and subjective moods can be related to variations in pilot landing performance. A statistically significant multiple R of .81 ($n = 26$, $p < .01$) was obtained with four predictors. In a separate study, pilot sleep patterns for a 1-week period were related to landing performance scores. Pilot intersleep intervals were highly correlated with day landing performance and found to be significantly different from non-flying personnel.

MEASURES OF PILOTS' TEMPORAL STATES OF READINESS

This research follows up previous results with more refined data collection procedures and instruments and integrates measures of a pilot's temporal state of readiness (sleep, mood, workload) with other pilot centered measures. Studies of two stress environments were undertaken: (a) carrier deployment, and (b) carrier landing qualification (CQ). Pilots from three attack squadrons embarked on the USS Kennedy (CV-67) during a recent Mediterranean deployment were the subjects for Phase 1 of the research program. Data were collected on daily activities for three major periods of time: a baseline nonflying period, a follow-up normal flying period, and a 72-hour high workload period of continuous flight operations. Daily activity data on pilot workload (flying and administrative) sleeping, eating, exercise, and mood, as well as pilot landing performance for the entire cruise, were collected and analyzed. Findings of interest indicate that pilot workload averaged 13 hours per day with 57 percent of the time spent in flight-related activities. When flying increased, squadron administrative work was reduced proportionally. No group sleep pattern disruptions were noted although sleep duration rose as flight activity increased. More short sleep episodes (naps) during flight periods account for this increase. Performance findings were remarkable for their consistent high levels, especially in terms of night carrier landing performance.

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SOME EFFECTS OF TASK AND WORKSPACE DESIGN TRENDS ON CORRELATES OF JOB SATISFACTION AMONG TELEPHONE SWITCHBOARD OPERATORS

Operators of cordless switchboards report dissatisfaction with their job and perform less efficiently than operators of cord boards. To explore possible causal factors, 15 operators participated in a psychophysiological study of both working conditions. Cord operators were found: (a) to carry a consistently heavier workload of concurrent calls, (b) to be dramatically more responsive to diurnal fluctuations in call-traffic level, while maintaining more stable "caller waiting times" and "effective call connections," (c) to exhibit this advantage without displaying higher levels of physiological stress, and (d) to display consistently higher levels of psychological well being. It is concluded that the cord operators' greater job satisfaction derives mainly from the substantial advantages their flexible system provides them in attaining and maintaining a high quality service.

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WORKLOAD PROBLEM ASSESSMENT

The Air Force function for this effort is to research operational aircrew workload and advanced methods for assessing the workload expected in future vehicles. A problem has occurred due to the neglect in developing assessment methods which are sensitive to workloads in advanced control and display systems. The objective is to maintain familiarity with workload assessment technology, to have total awareness and understanding of current operational workload problems, and to study innovative workload assessment methods for their applicability to crew systems engineering. This effort will contribute knowledge needed to fully understand operational workload problems such that the crew systems interface areas requiring further study can be identified. Operational crews from the major commands were interviewed in FY80 and workload related flight problems identified. A data base of operational workload problems was created in order to identify crew system problems that should be addressed in the development of future vehicles. As a result of this work effort, existing workload problems are identified for existing system operation, allowing for their study and resolution prior to their repetition in future systems (AFWAL-TR-80-3011). Such insight into current workload problems and the awareness of improved workload assessment methods will result in better and more cost-effective methods of evaluating crew workload as part of the crew systems development process. This work effort has been completed.

CREW SYSTEM DESIGN AND EVALUATION METHODOLOGY

The Air Force function supported by this work effort is the research and development of the crew system interface for advanced airborne weapon systems. As aircraft missions have become more complex, so has the crewstation design. The point has been reached where the crew system interface and its optimization can significantly impact the pilot's ability. This means the crewstation must be designed as an integral unit and that a variety of design evaluations are necessary to assume the design is optimized. In other words, the total evaluation must address all the issues (e.g., workload, reliability, performance, fatigue, task allocation, etc.), not just one or two. The objective is to establish and maintain an awareness of the complexity of total crew system design and evaluation and to become familiar with methods that exist throughout the R&D community, and to study innovative evaluation methods for their applicability to the crew system engineering process. This in-house effort will consist of literature reviews and data base searches in order to document the range of design and evaluation methods, their constraints for application, and their value as a design or evaluation tool. The crew system engineering process will be documented in TR format. Periodic, regular communications will occur with other DoD organizations in the area of crewstation evaluation techniques. As a result of this work effort, USAF weapon systems will be more fully evaluated from the position of the crew system interface. By identifying the range of design issues and methods by which to resolve them, better and more cost-effective evaluations can occur.

TAACE WORKLOAD PREDICTION

This contracted effort applied an analytic method known as the Control and Displays Evaluation Model (CODEM) to flight deck avionics improvements which resulted from AFWAL/FIGR's Tanker Avionics and Aircrew Complement Evaluation (TAACE) Program. Specifically, CODEM was used to evaluate the capability of the TAACE improvements to perform the rendezvous and in-flight refueling segments of the KC-135 mission. (TAACE data were utilized because the underlying intent of this contract was to apply CODEM to a previously, independently evaluated design for the purpose of validating the CODEM concept and sensitivity. This evaluation will occur independent from this effort.)

TAACE, which supported the USAF KN-135 Modernization Program, sought to establish the design criteria for the controls and displays of the improved flight deck avionics in the event the crew of the KN-135 is reduced by eliminating the navigator. The study involved the analysis of the new flight deck hardware designed for the KN-135; the application of Northrop's CODEM Program to generated crew task complexity; or workload, profiles, and the identification and validation of changes which, according to the profiles, would further reduce the crew's workload.

The CODEM results indicated that the flight deck of the modernized KC-135 aircraft can be operated satisfactorily in the rendezvous and in-flight refueling segment of a tanker mission with only a pilot and a copilot. The study also established that, on the basis of the CODEM analysis, the new flight deck avionics equipment elements did not cause unacceptably high crew workloads during the mission segment studied. The technical work has been completed and a technical report is being processed for publication.

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DEVELOPMENT OF A SHORT-RANGE AIR DEFENSE SIMULATION FACILITY AND A CREWMAN PERFORMANCE DATA BASE

Background

Studies are currently being undertaken to establish air defense command and control system requirements essential to the accomplishment of the air defense mission and to evaluate equipment performance and doctrinal concepts. An important critical part of the above system requirements is information concerning Short-Range Air Defense (SHORAD) weapon system personnel detection and recognition capabilities. This information is, however, difficult to obtain because of the high cost of live aircraft support and of the nonavailability of foreign aircraft.

During the interval of 1964 through 1976, research aimed at developing a data bank concerning the capabilities of operators of forward area air defense weapons to detect, identify, and estimate the distance of low flying aircraft was conducted. The studies had to be conducted, however, in a part

task evaluation environment. That is, each of these critical tasks was studied in isolation from the other components of the total operational sequence. Part task research only was conducted because techniques for measuring the effectiveness of the total engagement sequence were not economically feasible. As a result, there is a lack of information concerning an operator's abilities in performing part task components when they are embedded in whole task performance requirements.

Research

The Army Research Institute has initiated a research program oriented toward the development of a facility which realistically simulates the SHORAD engagement environment and the generation of a data bank of information concerning operator performance.

Past Research

The effort thus far has consisted of a paper-and-pencil feasibility study of the applicability of low cost simulation for presenting the SHORAD environment. In Task 1, parameters which must be included in the simulation of the SHORAD engagement environment were identified. During Task 2, low cost simulation approaches were evaluated for their relevance for the SHORAD environment. Three sets of data that will be necessary to collect when assessing operator performance capabilities were identified in Task 3. Instrumentation to gather data was also detailed.

Present Research

The present research effort will occur over the course of 3 years. Year 1 research is directed at fabricating a scaled dynamic flying model aircraft facility and evaluating the validity of the simulation. The orientation of the research in year 2 will be primarily to gather baseline data. Year 3 research will have the main purpose of investigating the effects of cueing and early warning on detection and recognition.

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DEVELOPMENT OF ADDITIVE WORKLOAD SCALES

Fundamental measurement theory is being applied to develop additive scales of mental workload. A technique has been developed to equate the workload of different types of tasks without making arbitrary scaling assumptions about the relationship between task performance and mental workload. The additivity assumption is being tested both in a secondary task framework and in a subjective scaling framework. Currently, a battery of tasks is being evaluated.

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Current efforts include development of subjective self-report scales of perceived operator fatigue for aircrew and ground crew; subjective self-report scales of perceived operator and anxiety states; electrophysiological techniques for the assessment of attention lapses associated with changes of alertness for aircrew; electrocardiographic techniques for in-flight assessment of pilot workload; and methods for assessing the field applicability of various promising laboratory methods of assessing workload presently under development at the Armstrong Aerospace Medical Research Laboratory. Basic research efforts are presently directed toward examination of the components of complex decision making tasks for their individual component susceptibility to the effects of stressors associated with varying demand schedules and unusual work/rest schedules; development of metrics based on eye blink and eye movement which can be used to index lapses in operator attention and the onset of fatigue likely to affect decision making and information processing of the type required in the operation of military aircraft, examination of the potential for time series analysis of electroencephalogram and electroculogram data for indexing a pilot's ability to perform information processing and decision making, particularly as it is affected by repeated sorties within a given day; and examination of the potential of sequential optimal control models for becoming a means to index piloting behavior in the presence of high cognitive processing workload demand under conditions of repeated missions in a single day.

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COMMAND CONTROL WORKLOAD

Workload assessment as included in evaluations of the adequacy of human engineering in operational Air Force Command Control Systems. Subjective workload scales are included in crew opinion surveys to supplement direct observation and measurement of primary task performance. Primary task measures include frequency and duration of crew interactions, telephone/radio communications, display viewing and adjustment, and checklist use. Indirect measures of task loading are derived from counts of the classes of information input/output identified in functional analyses.

Video/audio tape recordings facilitate assessment of workload indicated by overt behavior. Correlational analysis is used to obtain estimates of the amount of variance in judged workload accounted for by various task activities. Results are used as a partial basis for recommended human engineering design improvements including changes in procedures, work place layout, performance aids, task allocations, etc.

SYNTHETIC DATA SYSTEM

Industrial and engineering methods have been evaluated to determine feasible candidates for adaptation to Air Force crew workload assessment and allocation. It was determined that a combination of time synthesis methods and standard data systems was most appropriate. However, significant development is required. Deficiencies of systems currently used for industrial purposes are: (1) lack of consideration for divided attention effects, and (2) inadequate data on performance time distributions. Data were collected on motor perceptual tasks, perceptual mediation tasks, display reading, and communication as a first step toward data base development. Results indicate that a "synthetic data system" is feasible and that it could be combined with computer system simulations and computer aided design to form a viable approach to workload issue resolution both during and after system development. Contractual support for this effort was provided by Professor James Buck, formerly of Purdue University, now at the University of Iowa. Documentation is being prepared for this effort.

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DEVELOPMENT AND TRANSFER OF TIME-SHARING SKILLS

Performance on two different task combinations was examined for evidence that time-sharing skills are learned with practice and can transfer between task combinations. One combination consisted of two discrete information processing tasks, a short-term memory task and a classification task; the other consisted of two identical one dimensional compensatory tracking tasks. Three groups of 16 subjects were employed in the experiment. The first received dual task training on both combinations; the second received single task training on the discrete task combination and dual task training on the tracking combination; the third received dual task training on the tracking combination only. Evidence for distinct time-sharing skills was found in both combinations using a new technique designed to separate improvements in time-sharing skills from improvements in single task performance. Transfer of time-sharing skills also was found. Several fine grained analyses performed on the data from the discrete task combination and a control theory analysis of the tracking data indicated that skills in parallel processing were learned in each combination and transferred between them.

INDIVIDUAL DIFFERENCES IN DUAL TASK PERFORMANCE

Eleven right-handed males participated in an experiment examining individual differences in multiple task performance. Three task combinations were used in the study. The first was composed of a memory task and a classification task. The second consisted of two identical one dimensional compensatory tracking tasks. The third was a dichotic listening task. On day 1 of the experiment, the subjects practiced each task alone. On days 2, 3, and 4, they performed primarily under dual task conditions. Periodically, however,

dual task practice was interrupted to reassess single task performance. All dual task data were analyzed first to determine when stability occurred. Each subject's stabilized data from the tracking-tracking and memory-classification combinations then were corrected for the appropriate single task baseline. Finally, the subjects were grouped according to which of three response strategies they used to perform the memory-classification task combination. These strategies were a massed strategy (in which the subject would emit a series of responses to one task before responding to the other), an alternating response strategy, and a simultaneous response strategy. A two-way repeated measures MANOVA conducted on the stabilized adjusted data indicated both a significant effect of trials and groups. Possible sources of the between group differences are discussed.

RESIDUAL ATTENTION AS A PREDICTOR OF PILOT PERFORMANCE

Sixteen student pilots performed a task combination consisting of a choice reaction time task at one, two, and three bits of information and a one dimensional compensatory tracking task. Cross adaptive logic was used to keep performance on the tracking task constant, casting the between-subject variance into the choice reaction time task. Scores on this combination were correlated with performance on flight checks administered after 10, 20, and 30 hours of flight training. The multiple correlation between performances on the flight checks and the task combination increased as the students progressed through flight training. The usefulness of residual attention as a predictor of pilot performance is discussed.

A COMPARISON OF SINGLE AND DUAL TASK
MEASURES TO PREDICT PILOT PERFORMANCE

An experiment comparing the predictive validity of single versus dual task measures is reported. Fifty-seven males received two trials on each of two identical one dimensional compensatory tracking tasks. The subjects then attempted to perform the tasks concurrently for 25 trials. Finally, they performed each task alone for one trial. The subjects then were given a short basic flight course consisting of ground instruction and practice in a GAT-2 simulator. After completing the course, the subjects were asked to perform four repetitions of a descent, a descent followed by a stall, and a level turn. Performance was scored by an instructor and an observer. Performance in the simulator then was correlated with performance on each tracking trial. The predictive validity of the early single task scores decreased with practice while the dual task validity increased throughout the testing session. However, the predictive validity of the late single task scores was almost as large as that of the late dual task scores. Possible explanations for the results are given.

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AN ANALYSIS OF THE PROCESSING REQUIREMENTS
OF A COMPLEX PERCEPTUAL-MOTOR TASK

Current concerns in the assessment of mental workload are discussed, and the event related brain potential (ERP) is introduced as a promising mental workload index. Subjects participated in a series of studies in which they were required to perform a target acquisition task while also covertly counting either auditory or visual probes. The effects of several task difficulty manipulations on the P300 component of the ERP elicited by the counted stimulus probes were investigated. With sufficiently practiced subjects, the amplitude of the P300 was found to decrease with increases in task difficulty. The second experiment also provided evidence that the P300 is selectively sensitive to task relevant attributes. A third experiment demonstrated a convergence in the amplitude of the P300s elicited in the easy and difficult versions of the tracking task. The amplitude of the P300 was also found to covary with measures of tracking performance. The results of the series of three experiments illustrate the sensitivity of the P300 to the processing requirements of a complex target acquisition task. The findings are discussed in terms of the multidimensional nature of processing resources.

P300 AMPLITUDE AND RESOURCE ALLOCATION

These studies were designed to assess the relationship among subjective effort ratings, the amplitude of the P300 component of the event related brain potential (ERP), and task performance within a dual task paradigm. Subjects performed a step tracking task along with a tone discrimination task. Tracking difficulty was manipulated by varying the number of dimensions to be tracked, and by changing the control dynamics in an orthogonal design. ERPs were digitized to secondary task tones and to primary task step changes. Effort ratings and root mean square tracking error measures were obtained in each of the experimental conditions. Secondary task P300 amplitude decrements were related to increased system order in both one and two dimensions, while the dimensionality variable was associated with decrements only in higher order systems. A similar pattern of primary task performance decrements was also observed. Under dual task conditions, primary task P300s showed a complementary pattern of amplitude changes to those observed for the secondary task P300s. These data support the notion of reciprocity between primary and secondary task resources.

COGNITIVE PSYCHOPHYSIOLOGY LABORATORY

The primary mission of the research carried out in the Cognitive Psychophysiology Laboratory is to develop an understanding of the event related brain potential (ERP) so that it can be used as a tool in the study of cognitive function and in the assessment of man-macine interactions. To

this end, we have recently been conducting studies that fall into five, not altogether distinct, categories as follows:

1. The elucidation of the functional significance of ERPs in relation to memory.

2. The use of ERPs in studies of cognitive workload.

3. The use of ERPs in studies of mental chronometry.

4. The use of ERPs and performance measures to map the changes in cognitive strategies and capabilities which occur during aging.

5. Methodological studies.

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MEASURING SYSTEM EFFECTIVE OPERABILITY

A technique for measuring the effective operability of major air systems [the Mission Operability Assessment Technique (MOAT)] has been developed. MOAT combines the Pilot Task Inventory (PTI) approach with Multiattribute Utility Theory (MAUT), which is used to hierarchically organize and determine the importance of tasks and Psychological Measurement Theory and Scaling techniques, in particular Conjoint Measurement and the Delta Method of Scaling. System Effective Operability is defined as the weighted sum of the operabilities of the individual tasks. The weights reflect the individual task's criticalities as well as the importances of the various aircraft phases, subphases, and duty levels which are bases for the hierarchical organization of tasks. The operability of an individual task is an additive combination of workload and technical effectiveness. Measurement theory and scaling have been utilized to show that an additive combination is appropriate and to determine the underlying scales. When computerized, MOAT allows the rapid identification and determination of the relative magnitudes of system operability deficits.

A DECISION-ANALYTIC AID FOR AVOIDING COGNITIVE OVERLOAD

Decisions and Designs, Inc. (DDI), has proposed an approach to workload management that uses a cost/benefit analysis as its underlying principle. The commander or manager of a complex system, such as a submarine or an air traffic control center, is viewed as having a limited cognitive capacity which must be allocated among competing demands on his attention. When the total demand exceeds capacity, he must either shed some of his load or run the risk of a breakdown in his performance. Cognitive load can be shed in a variety of ways such as selective attention, task simplification, or responsibility delegation. However, each of these techniques is likely to produce a poorer result than would be expected if the commander's full attention was devoted to the task. Thus, shedding cognitive load involves a cost in that it will produce poorer performance and a benefit in that it reduces the demands placed on the principal decision maker. Using a model

of the costs and benefits associated with shedding cognitive load, a computer aid could help a decision maker determine which of his tasks are most critical. The aid could help determine how and when to delegate responsibility. As necessary, the aid could help allocate a decision maker's cognitive capacity over the tasks that must be performed. In these ways, the aid could help avoid cognitive overload and enhance an individual's ability to manage a complex technological system.

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TACTILE DISPLAY APPLICATIONS

The evaluation of a new tactile display concept required workload comparisons between visual and tactile display devices and between alternate tactile display designs and modes of operation. Critical tracking and cross adaptive subcritical tracking tasks developed by Jex et al., have been refined for these purposes. These workload oriented display assessment procedures are part of a program to develop tactile displays for operational helicopter applications.

GENERAL PURPOSE AND SIMULATOR ORIENTED WORKLOAD MEASURES

A long-term research objective is to develop a variety of workload assessment techniques for general use in flight simulator research and other R&D projects bearing on helicopter design and employment by the Army. The approaches under investigation include secondary task time estimation, vocal measures of stress, primary and secondary task performance in various continuous and discrete tasks, and analytical procedures for task analysis. The goal is to establish a variety of workload measures to support Army aviation by making tactical helicopter crew workload a more predictable and manageable parameter of system design.

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WORKLOAD MEASUREMENT/PREDICTION METHODOLOGY

Develop workload assessment/prediction methodology for commercial and military aircraft operability certification. Investigate the utility and sensitivity of various human performance and physiological parameters for

scaling operator workload in realistic crew/aircraft/mission contents. Both analytical and crew-in-the-loop simulation techniques are used.

WORKLOAD ASSESSMENT - PICTORIAL FORMAT DISPLAYS

A series of part task and full mission flight simulations is currently being performed to evaluate pictorial formats as a means of presenting essential information to pilots and weapon systems operators in two-seat aircraft. This work, being performed under contract to the Flight Dynamics Laboratory, Wright-Patterson AFB, began in April 1984 and is scheduled to run through June 1986. Both monochrome and color versions of pictorial formats for flight control, navigation, weapon status, systems status, tactical situation awareness, and emergency procedures will be evaluated. Evaluation criteria will include a number of primary task performance measures appropriate to specific segments in air-to-air and air-to-ground missions and the Subjective Workload Assessment Technique (SWAT) for estimating levels of pilot mental workload. A total of 16 operational Air Force crews will participate in this study.

WORKLOAD ASSESSMENT - VOR/ILS AND MAP/ILS NAVIGATION COMPARISON

A full mission visual flight simulation study was conducted as part of the FAA flight deck certification effort for the Boeing 757 and 767 airplanes. Primary task performance measures and pilot opinion data were used to compare crew workload for two navigation modes: VOR/ILS and MAP/ILS. All flights were flown manually with each of five crews flying an equal number of VOR and MAP flights. VOR stations were automatically tuned in the MAP mode and manually tuned in the VOR mode.

Primary task performance measures included continuous flight path control, discrete motor activity, communication activity, and eye fixation and scan patterns. Navigation mode had no systematic influence on steady state altitude control, touchdown performance, or proportion of flight time devoted to performing discrete manual tasks or communication tasks. Horizontal flight path control was steadier and more precise in the MAP navigation mode than in the VOR navigation mode. Visual performance in both the MAP and VOR modes was characterized by the "basic T" scan pattern. More time was spent attending to the horizontal situation indicator in the MAP mode than in the VOR mode. This difference, associated with longer but not more frequent fixations, reflected the increased information content of the next electronic map display in comparison to the compass display. Analysis of pilot questionnaire data indicated general agreement among pilots that workload was lower for the MAP mode.

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SUBJECTIVE WORKLOAD ASSESSMENT

In many applications of subjective workload measurement techniques, practical constraints make it desirable or necessary to delay completion of

subjective ratings until some time after actual task performance. This raises a question concerning the possible effects of such delays on the accuracy of subjective ratings. On the basis of the memory literature, it can be predicted that some loss of information will occur at relatively short retention intervals, but little data currently exist that address the specific relationship between retention interval and accuracy of subjective ratings of workload. A series of studies has been planned to examine the retention interval workload rating relationship. At present, the first study is underway. In this initial study, subjects perform an information processing task that requires that they update and recall the status of several continually changing categories of information. Subjects complete a subjective workload rating scale either immediately after the task or at one of two retention intervals. Immediate ratings will be used as the baseline to assess the effects of retention interval on the delayed ratings. Results of this first study will be used to structure subsequent efforts.

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INSTRUMENT SCANNING BEHAVIOR AS AN INDICATOR OF PILOT WORKLOAD

This is an investigation of the relationship between an aircraft pilot's visual scanning of instruments and his level of mental activity during a simulated approach and landing. This study is motivated by the increasing concern in several areas of man-machine interaction with the effects of changes in manual control and monitoring procedures on mental workload. This concern is particularly keen with regard to airline pilots, air traffic controllers, power plant operators, and personnel in control of large ocean going vessels, since the cost of error can be quite high in any of these man-machine systems.

Visual scanning behavior plays an important role in each of these systems, since the operator will typically be required to monitor a number of instruments which display system state variables. In each of the above roles, the human acts as a decision maker, a planner, a manual controller, a monitor, and an event detector. His ability to perform these tasks is generally influenced by their nature, number, and temporal arrangement; by his general physical and psychological state; and by the occurrence of unusual or rare events such as mechanical failures, bad weather conditions, etc. Ideally, a human operator's job should be designed in such a way as to require an appropriate fraction of the operator's capacity. To accomplish this design objective, however, the designer must have a method at his disposal of estimating the expended capacity under different conditions. While there exists a number of these methods, none is sufficiently benign and noninvasive to be used in the field (for instance, in an airliner's cockpit in flight). Consequently, we have set out to develop an estimator of mental loading, based on the operator's visual scan pattern.

In the current work, experiments were conducted in a Terminal Configured Vehicle (TCV) fixed base flight simulator at NASA Langley Research Center. Three NASA test pilots were presented with a piloting task, an arithmetic task designed to vary mental loading, and a side task for calibration of the mental loading task. The pilot look point was obtained by using a highly modified Honeywell oculometer system, and the pilot's eye scan of the instruments was recorded. The piloting task involved flying a curved Microwave Landing System (MLS) approach from a specified waypoint to touchdown.

The mental loading task was chosen so as not to interfere with the visual scanning of the pilot while providing constant loading during the approach. This was accomplished by having the pilots respond verbally to a series of evenly spaced, three-number sequences. The pilot was told that he must respond to each three-number sequence by saying either "plus" or "minus" according to the following algorithm: first number largest, second smallest = "plus"; first number smallest, last number largest = "plus"; other = "minus." The numbers were recorded at 20-second and 10-second intervals. These intervals had been determined empirically to vary mental loading under a similar piloting task.

The workload measuring side task employed two lights, one mounted above the other, placed just outside the pilot's peripheral view above the instrument panel. The lights came on at random intervals between 1 and 3 seconds and remained on for 1 second. The pilot was told to turn the lights off by using a three position rocker switch on the control grip (moving the switch up turned the upper light off, down turned the lower light off). This was done only when the pilot had time left from performing the primary task of flying the airplane. Thus, the number of correct responses to the lights saved a measure of the residual capacity of the pilot from which a workload index could be calculated.

A computer algorithm has been developed to obtain the first-order, discrete-state, discrete-transition, Markov model for each pilot's scanning patter. It is assumed that workload is constant within each of the six approach segments since the piloting tasks are essentially constant over each segment. This allows comparison of the instrument transition matrices for each segment with those obtained under different loading conditions. The relationship between visual scanning and workload is given by the change in the elements of these matrices as loading varies. Higher order Markov models may also be used to provide a more accurate description of the processes taking place.

MENTAL WORKLOAD IN DECISION TASKS

The importance of an operator's mental workload in manual control tasks has been increasingly recognized in recent years. As a consequence, a number of mental workload evaluation methods have been developed to serve as system design tools for tasks in which the human serves as a control element or in which he fills a supervisory (monitoring) role. These methods include performance measures, identification of fractional-attention parameters in analytic models, secondary tasks (reserve capacity) techniques, subjective scaling, and measures of correlated physiological variables.

Research is needed to extend the state of the art from the realm of manual control to that of decision making. With the increasingly evident shift of the human role from that of a manual controller to the executive level of a decision maker, an understanding of the relationships between the demands imposed by decision making tasks and the resulting cost in mental workload is essential.

Our approach is to construct an appropriate decision task whose level of complexity and difficulty can be controlled in the laboratory. Methods will be developed of measuring and quantifying the decision maker's mental workload in an experimental context. In parallel, the Optimal Decision Model (recently developed in our laboratory) will be expanded to account for task complexity and for the effects of the decision maker's workload level. The workload evaluation techniques will be of two categories: (1) reserve capacity index, and (2) performance measures, in which the decision maker's performance (rate of incorrect decisions, for instance) co-varies with his mental workload. The independent (i.e., experimental) variables include imposed decision rate, processing time requirements prior to decision making (i.e., complexity), number of alternatives, etc. The net objective is the construction of a canonical workload task that is readily calibrated in terms of noninvasive measures.

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The workload assessment of techniques used in the design, development, and certification phases of a commercial airplane program address two basic issues, timeliness of crew actions and ease of operation. The crew must be able to complete all necessary tasks with sufficient reserve time to accommodate unexpected events. Further, the mental and physical effort associated with each task must not place undue stress on the crew. Both objective and subjective methods are used to assess the impact of the flight deck design in these areas. Analysis, simulation, and flight test, used singly or in combination, have proven to be effective techniques for addressing a variety of workload problems. Analytic techniques are of particular interest to the aircraft manufacturer since hardware suitable for full-scale simulation or flight test is not available until late in the development cycle.

Timeliness analysis is the basic means of ensuring that the crew will have sufficient time to accomplish all of their tasks. During design and development, this technique is augmented by subsystems workload assessments which evaluate panel layouts and procedures, and by task-time-probability analyses which permit variations in task timing and crew performance to be examined. All three are comparative methods enabling a new design to be evaluated with respect to an existing airplane or subsystem well in advance of any hardware commitments. Following this phase, the physical aspects of workload, associated with hand and eye motion, are confirmed by observation using mock-ups, flight simulators, and/or flight test.

The multidimensional nature of what is commonly called mental workload requires assessment techniques which provide attribute profiles, not a

single index. In this regard we have found specialized subjective questionnaires and rating scales to be the most effective means for addressing mental workload. While subjective assessment methods are very useful, they cannot provide information in advance of hardware availability. We are experimenting with information-theoretic estimates of cognitive workload as a means to provide a preliminary evaluation of mental task loading. Such an estimate can provide a common measure for alternative display and control devices, allowing for a trade-off between them.

Commercial aircraft workload is qualitatively different from that associated with high performance military aircraft. Commercial aircraft development is evolutionary--each new aircraft flight deck draws heavily on past experience. The population of pilots flying commercial aircraft changes very slowly. The fundamental tasks and decisions expected of the flight crew remain largely the same from one vehicle to the next. It follows, therefore, that new workload assessment techniques will not have a radical impact on new designs. The primary benefits to be expected from new assessment methodologies are improved understanding of the basis for particular design decisions and greater efficiency in the design process.

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BIOCYBERNETICS/WORKLOAD

Optimum man-machine sharing and control of increasing information processing loads in high data rate environment will be provided by means of new biocybernetic techniques. The machine operator's psychophysiological responses will be displayed to machines noninvasively, on line in real-time via an automated, adaptive feedback loop. Research emphasis will be given to coding of brain evoked potentials by electrophysiological and neuromagnetic means. The brain wave signatures determined across a broad spectrum of sensory, cognitive, and motor activities will serve as templates for developing new neurologically based metrics of human operator performance. This will assist in identification and prediction of workload factors that influence both the design and operation of crewstations developed for critical training and operational missions.

This program is supported by intramural and contractual efforts at the Armstrong Aerospace Medical Research Laboratory under Colonel Robert O'Donnell to improve man-machine system design and under Andrew Junker in control theory analysis, and at the Air Force School of Aerospace Medicine under Dr. J. Miller in workload evaluation in multistress environments. The Air Force Office of Scientific Research extramural program is managed by Dr. Alfred R. Fregly.

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THE USE OF MENTAL PROCESSING TIME FOR THE EVALUATION OF EADI FORMATS

Integrated displays are commonly evaluated by dynamic tests in flight simulators using secondary task performance measures and subjective reports as the basis for evaluation. Both of these measures are of questionable validity when applied to mental workload quantification because of test artifacts, biases, etc. This project evaluated an alternative approach that has resulted from several years of mental workload research at the Douglas Aircraft Company. In this approach, mental workload is defined as the conscious mental processes involved in work and quantified as the time required to perform the mental processes. Three versions of an EADI were evaluated by means of discrete tests of the time required for subjects to obtain various kinds of quantitative and qualitative information from static CRT displays. The results indicate that this is an effective means of evaluating alternative display formats during early design phases.

MENTAL WORKLOAD QUANTIFICATION IN A CONTINUOUS TASK SITUATION

The purpose of this current project is to investigate objective methods of quantifying mental workload involved in obtaining information and making decisions from integrated displays. It is a follow-on to a previous investigation of the use of mental processing time measures to evaluate integrated displays in a discrete task situation. In the present project, subjects are given a flight plan to follow using controls and a dynamic CRT display of flight parameters. The mental processing time required to obtain information and make decisions will be measured by the method of subtracting and used to quantify the mental workload involved in alternative display formats.

PUPILLOMETRIC MEASURES OF MENTAL WORKLOAD

A recently completed study evaluated the use of pupillometer (Gulf and Western Applied Science Laboratories Model 1060-SRP) to assess mental workload. Subjects were given three levels of mental arithmetic under two conditions of manipulated stress in order to isolate purely automatic effects from central processing factors. The results are being analyzed.

PHYSIOLOGICAL INDICES

The efforts of this project are focusing on two major categories of physiological measurement. Electroencephalographic (EEG) and electroculographic (EOG) measures are being researched and developed as potentially unobtrusive indices of aircrew mental workload. A brief listing of research topics is given below with a description of the future direction for development. The laboratory for EEG and EOG recording is just becoming operational, and directions for future development may change dependent on what measures

prove useful for operational aircraft. Topics currently under study include:

1. Event Related Potential (ERP), P300 and P165. During simulated flying, ERPs will be elicited by probe stimuli which are aural warning events.

2. Iospotential Contour Mapping of Scalp Voltage Levels. Employing multiple electrode arrays, the contour mapping strategy of mental workload research attempts to develop concepts and metrics for describing focal brain activity.

3. EOG-Vergence Angle Measurement. Measurement of vergence angles of pilots with EOG techniques may permit an unobtrusive measurement of external vision in an operational aircraft. Under some circumstances, the percent time available for external vision (eyes outside the cockpit) may index overall cockpit efficiency.

4. EOG-Eye blink. Eye blink levels are being assessed as indices of workload during selected aircraft mission segments. Past efforts have investigated various general physiological responses such as heart rate and heart rate variability, pulse pressure, pulse volume, etc.

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MEASURING NEUROCOGNITIVE FUNCTIONS

The EEG Systems Laboratory performs basic research on measuring human neurocognitive functions. The emphasis is on developing and applying advanced methods of digital signal processing and statistical pattern recognition analyses to arrays of up to 64 channels of electrical field data recorded from persons performing highly controlled laboratory tasks. (Multichannel magnetic field recordings are also analyzed, as are depth electrode recordings from monkeys. These latter projects respectively involve collaborations with Sam Williamson and Lloyd Kaufman at New York University and Chuck Rebert at Stanford Research International.)

Current research is concerned with measuring neurocognitive patterns associated with maximal attention, short-term memory, perceptuomotor coordination,

and auditory versus visual processing of numeric information. The December 1984 issue of Psychophysiology contains a description of a recent experiment on a visuospatial motor control task. The October 1984 AFOSR Final Report for FY82-84 contains an up-to-date description of technical advances including methods of recording up to 64 scalp EEG channels, a single-trial ERP "scanning" analysis using statistical pattern recognition algorithms, an improved spectral eye movement filter, an algorithm for improved averaged ERP estimation, and examples of Wigner time frequency analysis of ERPs.

NEUROCOGNITIVE PATTERNS OF OPERATIONAL FATIGUE

Another project is concerned with measuring (and predicting) performance decrements consequent to operational fatigue. It is hypothesized that higher cognitive functions such as attention and short-term memory degrade prior to automated functions such as hand-eye tracking. The study is performed in collaboration with John Stern at Washington University in St. Louis, Hank Jex and Jim Smith at Systems Technology in Los Angeles, Jay Miller at the USAF School of Aerospace Medicine in San Antonio, and the 6512 Fighter Test Squadron at Edwards AFB. Following extensive development of the tasks, formal recordings were made from two fighter test pilots. Another three recordings are scheduled for early 1985. Each recording involves three sessions. The first is a practice and baseline session, the second is a fatigue session lasting up to 14 hours, and the third is a follow-up to measure recovery and control for learning effects. Each session consists of a number of simulated sorties lasting 90 minutes each. Each sortie consists of 40 minutes of a very high workload visuomotor-memory task, 30 minutes of a medium workload auditory memory task, and 20 minutes of subcritical and critical trackings. Twenty-six scalp EEG channels, two eye movement channels, muscle potentials, heart rate, and respiration are recorded, as are a number of performance measures. The data will be analyzed during 1985.

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DEVELOPMENT OF TECHNIQUE FOR MEASURING COMMUNICATIONS-RELATED WORKLOAD DURING TRANSPORT CATEGORY FLIGHT OPERATIONS (NASA-AMES)

General Physics (GP) developed a classification scheme for categorizing commercial transport communications. Further, GP applied analytic and subjective measurement techniques to quantify for the captain and first officer the workload imposed by these communications. Communication tasks were defined as a sequence of perceptual, cognitive, motor, and verbal responses initiated by the crew immediately following the transmission of an ATC instruction or message. Current airline captains and first officers participated in the study. Three measurement techniques were developed: (1) an information-theoretic technique to determine the bit values for perceptual, motor, and verbal components of each task; (2) a technique combining subjective estimates of cognitive workload with the results of the information-theoretic analysis; and (3) a subjective, rank-ordering of overall

demands. Highly significant agreement was found for the three techniques. These results provide a basis for selecting standard sets of communications tasks with variable loading characteristics. These tasks can be used to control communications related demands in future simulation research and also should serve as input to a data base of "workload-calibrated" flight tasks. The results of this project have been documented in a NASA technical report (NASA CR NAS2-11562, 1984).

ANALYSIS OF A PROPOSED WORK STANDARD FOR MACHINE-PACED MAIL DISTRIBUTION (AMERICAN POSTAL WORKERS UNION, AFL-CIO)

An adequate test of any proposed work standard requires that data pertaining to cost savings and productivity increases be balanced by data pertaining to job stress. At the request of the Union, GP conducted an independent evaluation of a new work standard for machine distribution of mail, focusing on the task performed by keyboard operators. Stress-related data were collected from crews of keyboard operators distributing mail according to the proposed work standard. These data were compared statistically with the data collected from matched crews performing a previously implemented mail distribution operation that was acceptable to both management and the Union. Five categories of data were included: work related, behavioral, postural, physiological, and subjective. In each of the measurement categories, the proposed work standard differed significantly from the existing work standard. The results of this project will be presented at the 2nd International Conference on Advances in Human Factors and Ergonomics, Purdue University.

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A GENERAL APPROACH TO THE MODELING OF TIME-SHARING BEHAVIOR

Human behavior under time-sharing conditions has been conceptualized within a framework inspired by concepts and methods from microeconomy, drawing an analogy between a manufacturer producing one or more products and a person with limited resources performing one or more tasks (1,2). This approach has been used to discuss possible interpretations of dual task performance wherein concepts such as task difficulty, demand, resource efficiency, and resource allocation have been clarified and defined. Special attention is devoted to the interaction between task characteristics, utility consideration, and voluntary control of resources. A survey of the literature and an analysis of existing models of human capacity have led us to outline a multiple resource approach in which the human processing system is assumed to have a number of mechanisms, each having its own capacity.

Our goal to study the joint effects of difficulty parameters and allocation policy resulted in the development of special experimental techniques to manipulate task priorities in concurrent performance. Response surface design has been employed to enable economical experimental design. Results

have been analyzed in terms of families of operating characteristics functions. Each function within a family depicts the trade-off of performance between two concurrently performed tasks for one condition of task difficulty, when resources are allocated in different proportions between the tasks. Experimental tests of these ideas have been conducted using two dimensional pursuit tracking tasks. These experiments lend support to the theoretical approach and demonstrate the utility of the methodological techniques.

Within this general framework, our experiments during the past year were designed to substantiate some of the ideas suggested in the earlier work, clarify the notion of multiple resources, and test the advantages and disadvantages of such an approach as compared with alternative interpretations of time-sharing interference. Two main studies motivated by the results of the first group of tracking studies were completed. In one experiment, pursuit tracking was paired with binary classification tasks. In another experiment, tracking was performed concurrently with variants of a data entry task that required the typing of letter codes.

The first experiment was designed to test the possibility that, although vertical and horizontal tracking may in many instances not compete for allocation of common resources, their coordination in joint performance taxes some other mechanisms. This involvement of a coordinating mechanism may not be relevant to tracking performance, yet appear in the performance of a third task. To test this hypothesis, we had subjects make binary classification of digits while tracking. To guard against possible effects of peripheral vision, digits were presented with a square that served also as the control symbol or the target symbol for the tracking task. Memory load was manipulated between subjects. Four conditions of tracking were used: single axis, dual axis, dual axis with feedback indicators, and dual axis with feedback indicators and unequal priorities on the two axis. Experimental results failed to reveal the existence of a coordinating resource. Similar decrements in binary classification and tracking performance were observed under single-axis and dual-axis tracking conditions. The additional requirement to allocate resources between tracking axes in unequal proportions also failed to affect classification performance. Thus, we have concluded that dual-axis tracking is probably not more costly than single-axis tracking in terms of any resource which is not used directly by tracking. An interesting outcome was the overall small deficits that were observed on both classification and tracking tasks under dual task conditions, which suggests that some of the large deficits reported in the literature are not due to capacity interference, but are caused by structural factors, such as peripheral presentations in a second experiment, two dimensional pursuit tracking was paired with a letter typing task in which letters appeared on the screen within the moving square of the tracking target symbol and had to be canceled by typing the correct letter code on a three-key keyboard. The difficulty of this task was varied by incrementing memory load (larger sets of letter codes) or increasing the difficulty of motor control (selection of more complex motor response patterns). The main findings of this experiment were:

1. In single task conditions, both difficulty manipulations yielded similar decrements in typing performance. Manipulation of memory load tended to cause larger decrements than motor control difficulty.

2. In dual task conditions, typing performance further deteriorated and decrements were monotonically related to task difficulty.

3. Difficulty of motor control interacted with the relative priority of the typing and tracking tasks while memory load produced a constant additive increment over levels of priorities.

These results confirm our previous argument that the locus of load in manual control tasks resides in the motor control requirements. The results also confirm the prediction that a multiple resource model in which difficulty manipulations tapping a common resource for concurrently performed tasks will interact with priorities, while manipulations tapping a resource relevant to one task only will result in additive effects. At present, we have several experiments underway that seek further clarification of the multiple resource notion and its practical implications for the description of time-sharing performance.

TRAINING PROCEDURES TO IMPROVE TIME-SHARING PERFORMANCE

While the study of general issues relevant to the modeling of time-sharing behavior is continued, our past year's and current research is marked by an increased involvement in questions related to training and development of time-sharing skills and the determinants of improvement in time-sharing performance. Is there a general time-sharing factor, whether inherent or acquired, with training? Are different strategies developed for the performance of tasks when performed singly or in time-sharing conditions? What are the consequences of training subjects in conditions in which intertask priorities vary dynamically? These are some of the questions addressed in our studies.

An experiment presently underway in our laboratory addresses the last of the above questions: training with variable priorities. Two types of training conditions are contrasted in this experiment. In one type, tasks are performed concurrently and no priorities are indicated, or equal priorities are emphasized and feedback indicators are displayed. In the second type, the relative emphasis on tasks is dynamically varied during training and subjects are required to allocate their resources in different proportions among the tasks. Training with fixed or unspecified priorities may encourage development of single optimal interweaving strategy or even integration of the tasks. Training with variable priorities disrupts integration but sensitizes subjects to the efficiency of resources and the consequences of their allocation in various proportions to the concurrently performed tasks. The effects of the two training schedules are investigated, employing pursuit tracking and the letter typing task described earlier. Partial analysis of the results shows that the group trained with variable priorities demonstrated larger improvement and higher levels of final performance than all other groups. When transferred to a new condition in which priority instructions and feedback indicators were eliminated, the group trained under variable priorities was superior to the other in its ability

to shift resources in order to protect constant performance levels under uninformed variations of task difficulty. The encouraging first results of these experiments are currently substantiated, and further experiments are being conducted.

CIRCADIAN RHYTHMS IN SUSTAINED ATTENTION TASKS

Short-term rhythmic fluctuations in alertness may be of special significance for the understanding of the behavior of subjects in sustained attention tasks. Oscillatory variations in the quality or speed of performance (sometimes referred to as lapses of attention) of radar observers, radio operators, air traffic controllers, drivers, pilots, etc., are frequently observed and most commonly treated as a random factor or considered to reflect noisy elements of the human processing system. It may be that the short-term variability in physiological activity and behavior can be linked together and shown to reveal regularity and organization.

Our research investigates the relationship between 90-minute rhythmic cycles of physiological processes and the performance of skilled psychomotor tasks. One of the interesting findings in this research is that the physiological cycle affects the accuracy of the movement, but does not affect their speed. Cyclical increases and decreases in the accuracy measure of motor movements were observed with a peak-to-peak interval of 100 minutes. Cycle deviation corresponded but was not synchronized with physiological processes. No such changes were observed in the speed of movements. Additional data are being collected for a wide battery of performance tasks. The discovery of circadian cycles in performance may lead to many applications in industry.

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PILOT WORKLOAD AND SCANNING BEHAVIOR

Pilot workload is composed of at least two components: the physical and the mental. Physical workload has been measured for years; however, the mental workload is more difficult to quantify. There is a possibility that eye scanning data can be used to quantify mental workload. Laboratory tests have been conducted which have attempted to establish such a link between mental workload and eye scanning data. In the tests, mental activity was altered by utilizing controlled levels of an auditory side task. The purpose of this auditory task was to rob time from the primary flying tasks. As the difficulty of the auditory task increased, the pilot's scanning behavior was affected. The pilots stared at the primary instrument and looked at the peripheral instruments less. In addition, their scanning sequences were disrupted with the increases in auditory task difficulty. This staring and sequence disrupting were more pronounced for the less skilled pilot. The performance on the flying task was poorer with increases in auditory task. The results of the laboratory tests suggest that it is desirable to use an auditory task to increase the overall mental workload

high enough such that system performance is affected, reflecting differences in display quality of procedure effectiveness.

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TIME ESTIMATION AS A SECONDARY TASK

For the past 4 years, different aspects of time estimation have been investigated with the goal of developing a series of easy to use flight-related indices of primary task load. To date, such variables as technique (counting, tapping, neither, etc.), method (verbal estimation, production), concurrent activity (tracking, monitoring, simulated aircraft and helicopter flight, etc.) and feedback (presence or absence, persistence) and the interactions among these factors have been studied by myself and a group of graduate students at Ames Research Center. The production method, particularly if subjects do not count and do not receive feedback, is the easiest to implement, although there are some methodological problems. Reports have been issued or are being written on the whole sequence of experiments. Few future experiments are planned except for full mission validation and cross-correlation with other measures of workload.

DEFINITION OF SUBJECTIVE EXPERIENCE OF WORKLOAD

In order to use subjective rating scales of workload, it is essential to determine:

1. What it is about an experience that produces the subjective experience called "workload" (e.g., doing more than one expected, fatigue, confusion, uncertainty, competition between tasks, etc.). Simply the task demands or resulting performance are not enough to explain the fluctuations in response and performance that are obtained with apparently similar tasks for the same subjects. It is often the circumstances under which the requirements are met, the expectations, experiences, motivations, training level, etc., of the pilot, and other so-called intervening variables that generate different ratings of subjective workload. Using a modification of the Sheridan/Tulsa moving boxes paradigm, in which the pilots will be required to perform a series of flight-related tasks reduced to the simplest possible elements presented with varying amounts of uncertainty, in various orders, under different circumstances in order to determine what aspects of the situation produce fluctuations in the subjective ratings of workload.

2. Determine how to retain the pilot's memory of his cognitive workload during a task, when querying him at the conclusion of the task with a subjective rating scale. It is clear that individuals' memories of how many decisions they made, how many times they monitored, perceived, calculated, estimated, projected, listened, etc., during an interval is very faulty and that the

cognitive components of preceding activity are the least likely elements to be represented in a pointed and detailed assessment of workload made retrospectively. Full mission simulations are planned in which pilots of a single engine aircraft simulator and a 747 simulator will be asked to give detailed evaluations of their cognitive processes during and after flights with different techniques, scales, and memory aides. The subjective rating scales that evolve from the two experimental approaches will be used by NASA and the FAA in their effort to evaluate the concept of providing pilots with a cockpit display of traffic control information (CDTI) and by other research programs at Ames.

SUMMARY OF WORKLOAD ASSESSMENT RESEARCH AT AMES RESEARCH CENTER

The workload assessment effort at Ames Research Center has been recently expanded and formalized into a separate program. The purpose of the program is to investigate, develop, validate, and standardize subjective and objective measures of pilot workload and performance in laboratory, simulation, and in-flight environments. In order to do this, we felt that the following questions should be addressed:

What role, if any, do fatigue and emotional stress play in the subjective experience of workload?

Does the term workload refer to the demands placed on an operator, the effort he expends trying to meet the demands, or his success in doing so?

Can pilots distinguish among different sources of workload, such as physical, perceptual, etc.?

What is it about the circumstances under which a task is performed that alters the subjective experience of workload?

How well can pilots produce reliable and valid subjective ratings of workload in retrospect?

The initial focus will be on the development of subjective rating scales, as these appear to have the widest application. A simple pilot opinion survey was recently conducted to obtain ratings of the total, perceptual, cognitive, and physical workload involved in general aviation flight. These ratings will be used to generate primary task situations, with different levels and dimensions of workload to serve as a test bed for the workload assessment program. The validity of this approach will be assessed with a series of simulation experiments in our GAT-1 facility in November. The results of this study will be described at Human Factors. Additional laboratory research has been completed in which a series of subjective rating scales have been used in conjunction with part-task simulations focused on cockpit display of traffic information issues. Cooper-Harper type rating scales, the rating scale proposed by Airbus Industries, the Pilot Workload/Technical Effectiveness Scale, and several sets of bipolar adjective scales were studied in this environment. The initial results of this work will be reported at IEEE in Atlanta later this month. Earlier laboratory research was completed in which simple manual control tasks were used to generate

different levels of task demands. Fifteen bipolar adjective scales were used to evaluate the differential effects of task demands (amplitude or frequency of the forcing function to be tracked), pilot effort (RMS stick activity) and performance ($RMSH_e/RMS_i$) on the experience of workload and related factors. The results of the first of two studies was presented by Kathy Bird at Annual Manual in June. Additional studies in this area are planned this winter in which cognitive and perceptual tasks will be used in place of the primary physical tracking task to obtain additional subjective ratings under different levels of task demands. Further simulations are also planned.

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ELECTROPHYSIOLOGY OF THE MOTOR SYSTEM:
VOLITIONAL VERSUS REFLEX MOTOR ACTIVITY

Description of Research Effort

A critical issue which must be addressed in neurobiologic coupling is the development of technology to separate volitional from reflex motor activity. A correlate of this is the technology for sensing the signals in an optimum, noninvasive way. Several motor "systems" are candidates for this effort; the oculomotor system is particularly attractive. This contract will address the two questions described above in laboratory studies and will, in addition, acquire descriptive data on individual differences, this latter issue being particularly significant for the selection portion of the Pilot Attributes program.

INDIVIDUAL DIFFERENCES IN NEUROPSYCHOLOGICAL MEASURES

Description of Research Effort

Neuropsychological assessment is the state-of-the-art psychologic evaluation technology. Test batteries have been developed and validated and are coming into increasing use. A variety of measurements per battery and across batteries is available. This effort will establish the baseline for exploring neuropsychologic measures in the Pilot Attributes Program. In this effort, the contractor will develop a catalogue of batteries and measures, extract statistics on these measures from published papers and/or data bases, make some educated guesses about the utility of these measures for our population (healthy, motivated 20- to 25-year-old candidates for UPI), and recommend further research.

STATISTICAL MODELS OF NONPREDICTIVE TRACKING
BEHAVIOR AS INDICATORS OF STRESS TOLERANCE

Description of Research Effort

The objective of this research is to determine precise statistical distributions of human perception and control in the performance of a nonpredictive

tracking task, and to examine how stressors influence these distributions. The emphasis is upon determining individual perception and control attributes which may be used to select pilot training tracks and enhance skills. Specific research efforts will include: (1) find the distinguishing characteristics of perception randomness and control randomness; (2) generalize the statistical descriptions for the perception and control random variables to joint probability density functions; (3) develop parameter identification techniques to determine model parameters and distributions for short duration tracking exercises; (4) determine standards for perception and control attributes; (5) model and find the statistical distributions for a two-dimensional nonpredictive tracking task; and (6) further develop a means of testing perception and control attributes.

Electrophysiology of the Motor System

Effectors

To conduct studies designed to identify unique characteristics of the effectors in the motor system which separate reflex from volitional activity and which show stability across a variety of conditions sufficient to become candidates for neurobiologic coupling (Pilot Attributes).

Tracking Enhancement in Target Acquisition

Conduct studies using the findings of a FY83 contract to identify candidate techniques to enhance the motor aspects of target acquisition.

Situational Awareness

Empirical Evidence

To conduct field studies on operational personnel (noninterference) in order to acquire empirical evidence that validates and extends the conceptual framework for situational awareness being developed in a SCEEE contract, FY83 (Pilot Attributes).

- "a prototype training program for situational awareness."

Approach

Prior research has identified the significant elements of situational awareness and has validated these elements in operational aircrew. In this effort, techniques to train for each element will be developed, the techniques will be integrated across all elements, and a prototype training program will be designed.

Cognitive Aid Training System

Objective

To develop a prototype training system to enhance aircrew skills in information processing, decision making, and problem solving.

Approach

Enhance the software of a system known as "Cognitive Aid," and tailor it specifically to meet the training requirements identified in the "Objective."

- "a first generation prototype of a neuromotor sensor system to shorten reaction time."

Approach

Evaluate the findings of earlier research identifying potential approaches; select not more than three; design appropriate systems; construct first generation prototypes; design and conduct demonstration "studies"; provide a quantitative evaluation of utility.

- "practical, simple measures of brain laterality as one part of a Pilot Attributes selection test battery."

Approach

Review findings from an earlier literature review; examine alternatives for data acquisition, performance testing, data reduction and read out, storage; develop not more than three breadboard devices, perform modest studies to demonstrate utility; make recommendations for incorporation into a Pilot Attributes selection test battery.

- "measures of workload tolerance which can be embedded in a Pilot Attribute selection test battery."

Approach

Develop an inventory of measures of workload tolerance, with specific focus on stability of individual differences across workload and operational stress conditions; select the most promising and develop prototypes; conduct modes demonstrations of utility, sensitivity, ease of application, and suitability for embedding in an "Atari-like" configured test battery; narrow the field of candidate measures; and make recommendations.

- "measures of attention 'skills' and 'power' which can be embedded in a Pilot Attributes selection test battery."

Approach

Develop an inventory of measures of attention, with specific focus on stability of individual differences across workload and operational stress conditions; select the most promising and develop prototypes; conduct modest demonstrations of utility, sensitivity, ease of application, and suitability for embedding in an "Atari-like" configured test battery; narrow the field of candidate measures; and make recommendations.

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PILOT MODEL BASED ANALYSIS OF HELICOPTER MISSIONS

An important problem in helicopter mission task analysis is the assessment of prediction of expected pilot-vehicle performance and associated pilot workload in accomplishing the mission objectives. However, existing methods for performance and workload evaluation and forecasting are highly empirical and lack a cohesive analytical structure or framework. In an effort to remedy this situation, the U.S. Army Aeromechanics Laboratory at NASA Ames Research Center has initiated a joint long-term program committed to the development of an analytical technology base for improved pilot vehicle performance and workload analyses.

Selection of an appropriate model structure for the human pilot is crucial to the success of any model based analytical methodology. Pilot model formulation must be based upon a thorough understanding of the mission objectives and their impact (as perceived by the pilot) on the tasks that the pilot must perform during the contiguous flight segments. The model structure should incorporate the essential elements of the pilot's information acquisition/processing, decision making, and control behavior within a systematic analytical framework.

The process of flying consists of performing a hierarchy of tasks corresponding to increasing levels of cognitive involvement. As a minimum, piloting tasks may be classified into two hierarchical categories: (1) lower level autonomous information processing and control tasks, and (2) higher level decision making tasks.

A hierarchical model for the pilot based upon the two level task decomposition has been developed and exercised.

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SUBJECTIVE RATING OF TASK DIFFICULTY

This report describes work done by the Human Factors Laboratory under Navy Subcontractor No. N00123-79-C-0159. The purpose of this work was to determine the reliability of several established rating scales in estimating cognitive workload. Results of this study indicate that ratings of task difficulty are significantly related to performance scores; and for task difficulty levels up to performance breakdown, ratio scale ratings are significantly more accurate relative to performance scores than are category scale ratings. Problems of implementing each type of scale are discussed. The use of such scales will allow for the cost effective assessment of workload imposed upon operators of any man-machine system, with special suitability for the test and evaluation stages of the developing F-18 air system.

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HUMAN FACTORS IN DESIGN AND EVALUATION OF AVIATION MAPS

An extensive program of work on workload in reading maps is included in a recent AGARDograph reviewing all known human factors work relevant to aviation maps. Mental workload is considered in relation to human capabilities and limitations, particularly of cognitive processing, in relation to task descriptions, and in relation to methods of measurement and assessment of maps. There is not a separate section on mental workload as such, but evidence on mental workload is related to the objective of designing effective aviation maps.

HUMAN FACTORS IN AIR TRAFFIC CONTROL

A continuing series of evaluations on proposed air traffic control systems and subystems for regions of the United Kingdom is conducted which normally employs measures of mental workload, most commonly subjective ones. A paper on mental workload (in Moray, 1980) related to air traffic control sets out the problem encountered in this research. Workload measurements in air traffic control are also covered in some of the papers, including my own, on air traffic control in the special issue of Human Factors in 1980 devoted to air traffic control. Measures of mental workload have generally proven unsatisfactory in practical air traffic control contexts. The main reasons seem to be the gulf between the theoretical interest in mental workload which is high, and the practical problem of mental workload which is not simply high but too high or too low, so that practical steps must be taken, in the form of system design changes, equipment changes, changes in instructions, changes in allocation of responsibilities, changes of facilities or changes of training, etc., to alter a workload level which is inappropriate and leading to inefficiency or other problems.

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TEST BATTERY

The purpose of this research project is to develop a test battery of psychological and physiological measures in order to evaluate both the level and type of workload found in a flight deck environment. As the measures are defined and evaluation methods developed, a series of part task simulations will be conducted to determine the utility and sensitivity of the selected measures. Performance measures and time line data will also be

collected during the simulations to be correlated with the workload data. All data will be used in the development of a workload assessment computer model for preliminary design evaluation.

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STUDY OF A SIMPLE CRITICAL TASK FOR MEASURING EFFECTIVE PILOT DELAY TIME WHILE TRACKING
National Aeronautics and Space Administration, Contract NAS2-2288

A closed loop compensatory tracking task was developed which yields a measure of the human operator's time delay characteristics while tracking, constrains his behavior to within very narrow limits, and provides a low variability indicator of the operator's tracking ability. The task is called the "critical task" because the operator is required to stabilize on an increasingly unstable controlled element up to the critical point of loss of control.

Study results showed that when operating near criticality, the subject's behavior was adequately represented by recently developed human operator describing function models and adaptation laws. Further, the extrapolation of describing function data to the critical level of instability showed that the operator consistently loses control at small, but finite, mean stability margins. The just controllable first order divergence was shown to be related dominantly to the operator's effective time delay, and secondarily to the nominal variations of his average tracking characteristics and to mid-frequency phase lags due to long period kinesthetic adaptation effects. It was also found that the human operator's characteristics do not change as the system input level is decreased; hence, the critical task yields a valid limit when excited solely by the operator's remnant. The effects on the operator of different control device types (force, spring, and free) were investigated and the differences in critical task scores related to the operator's describing function characteristics. Step reaction time data were compared with the continuous measures of effective time delay and the autopacer scores. A sample analysis to determine the number of autopace trials necessary to achieve a confident measure was made.

EXPLORATION OF CONNECTIONS BETWEEN PILOT-OPINION RATINGS, PILOT DYNAMICS, AND SYSTEMS CHARACTERISTICS
Air Force Flight Dynamics Laboratory, Contract AF 33(615)-3960

The purpose of this study was to determine the correlation between pilot and system dynamics on opinion ratings and to evolve a valid opinion scale lacking the deficiencies of past scales. To establish the effects of pilot and system dynamics and performance on opinion, recent data gathered under Air Force Contract AF 33(657)-10835, "Human Pilot Dynamics in Compensatory Systems," was used. The results of that study, which determine the operator's characteristics and behavior with dynamics representative of a number of idealized flight control situations, were correlated with existing opinion rating data. Thus, the effects of pilot gain, reaction time delay,

equalization, and neuromuscular system characteristics on opinion were determined. At the same time, a refined opinion scale (or scales) were evolved through a careful assessment of both objective and subjective pilot and system characteristics.

Although rating scales of varied forms have been widely used to estimate and evaluate handling qualities over the past decade, a number of deficiencies in both method and data base have been apparent. This investigation was aimed at overcoming many of these deficiencies by attempting to resolve the difficulties experienced with rating scales themselves and by extending and adding to already existing relationships between ratings and pilot/vehicle system parameters.

Rating scales have come under increasing criticism for problems related to wording ambiguity, the dual mission character of some scales, the nonuniformity in the distribution of descriptors across the scale, and the misuse of scales which has occurred when ratings have been averaged. Psychometric methods provide an approach to these problems and, in this study, were used to scale several phrases descriptive of vehicle handling qualities. Thus, quantitative characteristics were driven from contemporary scales through the use of a scaling technique known as the "Method of Successive Intervals," where data for the method were obtained from a survey experiment.

An experiment was conducted which added to available data relating Cooper ratings and pilot/vehicle parameters, and which also tested some potential alternate scale candidates. The correlation results indicate that ratings are probably based on performance and the degree of difficulty experienced in maintaining the performance. The difficulty is most easily represented by the pilot equalization required and the vehicle stick characteristics.

EXPERIMENTS FOR A THEORY OF MANUAL CONTROL DISPLAYS
National Aeronautics and Space Administration, Contract NAS2-3746

This research effort spanned several years and involved a long-range program to develop a comprehensive theory for understanding, analyzing, and improving the pilot's use of manual control displays. One facet of the program was to evolve efficient and analytical models for the pilot's tracking of quasi-predictable forcing functions (e.g., following the optical landing beam of an aircraft carrier plunging through deep ocean swells terrain-following flight over rolling countryside, etc.). As a part of the experimental program, a novel technique was used to force the subject (skilled instrument rated pilots) to scan two displays in a manner that is realistic yet controllable by the experimenter. This was done via a "subcritical" side task (stabilizing a slightly unstable first order plant), such that the time away from the side task (i.e., available for the main task) is limited by the time-constant of the divergence. In order to preclude parafoveal cues, eye movement signals were used to blank the nonfixated display in certain cases and some performance decrements were found. It was found that the pilot's average scanning, sampling, and reconstruction behavior can be accurately modeled by an adjustable quasi-linear describing function, plus an injected "scanning remnant" (observation noise) having wideband properties.

The model was validated by a series of experimental measurements of pilot scanning and control response in a simulated instrument approach. Seven subjects flew Category II-like ILS approaches in a six-degree of freedom fixed base DC-8 simulator at the NASA Ames Research Center. A conventional instrument panel and controls were used, with simulated vertical gust and glide slope beam bend forcing functions. Pilot eye fixations and scan traffic on the panel were measured using a recently developed eye-point-of-regard (EPRO) system. The EPR data were reduced for 31 approaches with a cross-section of subjects to obtain dwell times, look rates, scan rates, and fractional scanning workload. Simultaneous recordings were made of displayed signals, pilot response, and vehicle motions to permit their correlation with the eye movement results.

RESEARCH ON A NEW HUMAN DYNAMIC RESPONSE TEST BATTERY
National Aeronautics and Space Administration, Contract NAS2-4405

A battery of autopaced critical-instability tasks, subcritical tracing tasks, and step reaction time tests was developed to permit efficient measurement of the limiting human dynamic response properties. Standard test parameters for first-, second-, and third-order controlled elements (the latter requiring double-lead equalization) were given. Comprehensive "baseline" measurements were made on four well trained subjects (three were pilots) using a specially built controlled element computer and an on-line describing function analyzer.

The resulting data includes tracking errors, describing functions (and derived loop closure and model-fitting parameters), remnant, critical instabilities, and reaction times. A number of simultaneous psychophysiological measurements were also made. These include electrocardiogram, "instantaneous" heart rate, breath flow, electromyograms, average grip pressure, and palmar skin resistance.

These data showed consistent increases in the neuromuscular tension indicators during tracking. Breathing was usually faster and shallower. The average heart rate increased for only two of the four subjects but distinct increases in the cardiac "sinus arrhythmia" were noted, which were completely correlated with breath flow. Remarkably simple correlations were obtained between the critical instability and various other closed loop dynamic performance metrics. These tests and results constitute the foundation for a series of continuing experiments on effects of environmental stresses and workload.

Also as a part of this program, STI administered a tracking tasks battery during a 90-day confinement experiment to determine the physiological and psychological effects of long duration confinement in a space station atmosphere. The battery included a "clinical" test (critical instability tasks designed to measure a subject's dynamic time delay and a conventional steady tracking task, during which dynamic response (describing functions) and performance measures were obtained. The subjects were extensively trained prior to confinement and generally reached asymptotic performance levels.

Good correlation was noted between the clinical critical instability scores and more detailed tracking parameters such as dynamic time delay and gain-crossover frequency. The levels of each parameter spans the range observed

with professional pilots and astronaut candidates tested previously. The chamber environment caused no significant decrement on the average crewman's dynamic response behavior and the subjects continued to improve slightly in their tracking skills during the 90-day confinement period. Some individual performance variations appeared to coincide with moral assessments made by other investigators. The comprehensive data base on human operator tracking behavior obtained in this study demonstrates that sophisticated visual motor response properties can be efficiently and reliably measured over extended periods of time.

RESEARCH ON THE EFFECT OF DISPLAY PARAMETERS ON HUMAN CONTROLLER REMNANT
Air Force Flight Dynamics Laboratory, Contract F33615-69-C-1808

This study was a first step toward the long-range goal: to develop efficient analytical models for human controller remnant which were as useful as current quasi-linear pilot models in manual control/display systems design. This contract concentrated on selected single loop display situations in which remnant is predicted to be appreciable. First, using new theoretical guidelines, an extensive archive of remnant data as STI was reanalyzed to provide a data base for refining the remnant models. Then, a series of brief experiments was performed, using remnant sensitive displays such as quantized bar graphs, moving tape scales, and parafoveal displays. These experiments made use of the STI-developed controlled element computer and on-line describing function analyzer. In addition to describing functions and remnant spectra, subjective workload ratings and (where relevant) scanning workload were measured.

FLIGHT EXPERIMENT AND FLIGHT HARDWARE SPECIFICATION DEFINITION
National Aeronautics and Space Administration, Contract NAS2-6409

Contract NAS2-4405 brought the development of the critical tasks battery to a fruitful stage of application for laboratory research. The Mark II CTB has been used in the NASA-McDonnell Douglas 90-day confinement experiment and has been proposed for use under vibration stress and G-stress. An orbital version of this test apparatus has been proposed for a space experiment on human operator dynamics under orbital conditions. This contract involved completing the preliminary research and design, as required to proceed rapidly with the orbital hardware fabrication, should the proposed orbital experiment be approved. Flight experiments and hardware specification definitions include hybrid analog digital CTB mechanization, finalization of multiaxis workload test, and design specifications for orbital tester hardware.

The various tests in the battery were applied to a set of simulated space shuttle reentry experiments utilizing the Ames Research Center centrifuge. Effects of cardiovascular deconditioning were investigated via several days of bed rest.

ENGINEERING PSYCHOLOGY RESEARCH SERVICES
National Aeronautics and Space Administration, Order No. A-29602B

This program was part of an Army project, funded through NASA, to establish and develop new methods to measure, quantify, and predict helicopter aircrew workload. The effort provided background information to guide the

selection of R&D strategy for development and verification of this new methodology. It was coordinated with other contract and in-house technology assessments of workload measurement research using several basically different approaches. This part of the project concentrated on procedures which assess primary task performance in some manner as the basic element of a workload measurement procedure. To accomplish the objectives of this program, a comprehensive survey of the aerospace human engineering, behavioral sciences, flight simulation, and vehicle control literature was made to identify and review all such primary task measurement methods for vehicle operator workload appraisal.

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MENTAL WORKLOAD IN A SIMULATED DRIVING TASK

Tracking is one important component in car driving. That is why it is used as a paradigm in an experiment to test different variables as workload indicators. The difficulty of the main task is changed in three levels by varying the frequency of the forcing function of a velocity system with the one dimensional tracking task. Workload indicators are:

1. A unipolar graphic rating scale.

2. A secondary task where a pointer moves on a horizontal scale; the subject has to press a knob when the pointer enters a warning zone of the left and right end of the scale.

3. Different measures of heart rate and heart rate variability (time domain and frequency domain measures).

4. Primary task measures like steering reversals, steering activity.

The feasibility of these indicators is examined in terms of reliability, validity, and freedom of interference. Results show that the most valid workload indicators are the rating scale and the secondary task. Nevertheless, all of them have severe limitations. In subsequent investigations, the same workload indicators will be measured in experiments with a car driving simulator.

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A THEORETICAL APPROACH TO MEASURING PILOT WORKLOAD

This research uses theoretical models of attention to derive appropriate secondary tasks for the objective measurement of pilot workload in a moving base flight simulator. Asynchronous secondary choice reaction time tasks have been quite successful as objective measures of workload. Current research attempts to extend this to synchronous secondary tasks and to expand the types of secondary task that are used.

BIOCYBERNETIC ANALYSIS OF A HYBRID WORKLOAD MODEL

This research investigates both behavioral and psychophysiological responses in a psychological refractory period paradigm. We hope to relate reaction time, error rates as behavioral measures to heart rate, and P300 biocybernetic measures. Operator workload is controlled by varying interstimulus interval and response information using a modified partial advance information technique.

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PROJECTED WORKLOAD

The workload literature ordinarily studies the effects of load by a metric that deals with the amount of information that is presented/processed per unit of time over available pathways. In this way, functional reserve can be assessed. It is my intention to expand on the temporal demands of workload (presently limited to studies of keeping track, historically, of several things at once with changing status) by measuring how far into the future the controller of a system can predict. It is expected that functional reserve, so measured, will improve with practice.

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THE PROCESSING OF STIMULUS ATTRIBUTES:
EVIDENCE FOR DUAL TASK INTEGRALITY

Research on dual task performance has been concerned with delineating the antecedent conditions which lead to dual task decrements. Capacity models of attention, which propose that a hypothetical resource structure underlies

performance, have been employed as predictive devices. These models predict that tasks which require different processing resources can be more successfully time shared than tasks which require common resources. We suggest that dual task decrements can be avoided even when the same resources are required by both tasks, by designing the tasks so that the processing demands can be integrated. The conditions under which such dual task integrality can be fostered were assessed in a study in which we manipulated four factors likely to influence the integrality between tasks intertask redundancy, the spatial proximity of primary and secondary task displays, the degree to which primary and secondary task displays constitute a single object, and the resource demands of the two tasks. The resource allocation policy associated with these integrated dual task pairs is inferred from changes in the amplitude of the P300 component of the Event Related Brain Potential (ERP). Twelve subjects participated in three experimental sessions in which they performed both single and dual tasks. The primary task was a pursuit step tracking task. The secondary tasks required subjects to discriminate between different intensities or different spatial positions of a stimulus. Task pairs which required the processing of different properties of the same object resulted in better performance than task pairs which required the processing of different objects. Furthermore, these same object task pairs led to a positive relation between primary task difficulty and the resources allocated to secondary task stimuli. Intertask redundancy and the physical proximity of task displays produced similar effects of reduced magnitude.

THE EFFECTS OF PRACTICE AND TASK STRUCTURE ON COMPONENTS OF THE EVENT RELATED BRAIN POTENTIAL

The present study focused on the effects of, and the interactions between, practice and task structure on human performance. The development of automatic processing through consistent stimulus-response mapping (CM) was assessed by means of measures of reaction time and event related brain potentials. The subjects performed a visual search task in which they responded by pressing a button whenever a probe matched a memory set item. The variables manipulated in the study included the number of memory set items (1 or 4), the task structure (CM or VM), and the probability of occurrence of a memory set item (.2 or .8). Set size had a significant effect on RT in both CM and VM conditions prior to practice and in the VM condition following extensive practice. P300 latency mirrored RT, suggesting that the development of automatic processing substantially reduced stimulus evaluation time. The commonly observed relation between probability and P300 amplitude, with larger P300s elicited by infrequent events, was found in the VM conditions but not in the CM condition after practice. This suggests an attenuation of memory updating during automatic processing. Two different negative components were affected by stimulus mismatch. These components appear to reflect different degrees of mismatch processing in automatic and controlled processing tasks.

EVENT RELATED BRAIN POTENTIALS AS AN INDEX OF RESIDUAL CAPACITY DURING SKILL ACQUISITION

The focus of our new research project is to employ ERPs in conjunction with measures of overt performance (e.g., reaction time, accuracy, root mean

square tracking error) and subjective indices of cognitive workload to monitor changes in resource demands which occur during practice. The effects of practice on the allocation of resources between concurrently performed tasks will be examined in two different contexts.

In one case, ERPs will be recorded as subjects progress from an effortful, controlled processing mode to that of an automatic processing mode. Subjects will perform a modified Sternberg paradigm concurrently with a two dimensional pursuit step tracking task. Performance on one version of the Sternberg paradigm results in an automatic processing response after several thousand trials of practice [consistent mapping (CM)] while in the other version of the task subjects retain the controlled processing mode [varied mapping (VM)]. The changes in resource demands with practice and task structure will be monitored by both performance measures and ERPs. The second context will involve assessing the feasibility of employing ERPs as a real-time measure of residual resources during the acquisition of a complex perceptual motor skill. ERPs will be used both separately and in conjunction with performance measures to detect momentary shifts in resource requirements and to adjust the level of task difficulty on the basis of the processing demands imposed upon the human operator. Subjects will perform two tasks concurrently throughout the training period. The ERPs elicited by both the primary and secondary task stimuli will be used to adjust the difficulty of the primary task. The primary task, two dimensional pursuit step tracking, will be adapted by adjusting the system dynamics so as to maintain a constant level of workload.

If workload metrics are to truly be of use to designers of complex, semi-automated systems then the validity of the ERP based approach must be assessed in extra-laboratory situations. Therefore, a second goal of the research program is to validate ERP workload metrics in a more ecologically valid multitask environment than is commonly used. To this end, we will record ERPs as student and experienced pilots practice a variety of flight tasks in a fully outfitted ILLIMAC single engine aircraft simulator. ERPs will be recorded from discrete stimulus changes within the flight task as well as from secondary task events.

AVIATION RESEARCH LABORATORY

The Aviation Research laboratory (ARL) is located at the University of Illinois Airport (Willard Airport). The ARL is a rather unique research facility, in that it has access to approximately 160 student pilots in each academic year, two fully outfitted digital single engine aircraft simulators, over a dozen certified flight instructors, and a fleet of over 20 single engine aircraft. The research facilities include numerous microbased human performance monitoring stations and a portable PDP 11/73 based physiological recording system. Data analysis takes place on the micros and the PDP 11/73, as well as on a Harris 800 (Psychology Department) and a Cyber (University). In addition to the physiological recording and data analysis facilities available at ARL, several well equipped physiological recording systems are located at the Cognitive Psychophysiology Laboratory in the Department of Psychology. The research issues concurrently being addressed at ARL include the assessment of cognitive workload, manual control, supervisory control, behavioral neurotoxicology, and flight training.

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COCKPIT AUTOMATION TECHNOLOGY

The primary objective of this project is to develop and apply an innovative method for aircraft crew system design that assures efficient use of pilot abilities and makes the best use of cockpit automation. This project includes the compilation of a data base consisting of models, data, and measurement techniques relevant to crew system performance. This effort will include a review of models and measurement techniques pertaining to operator workload.

DEVELOPMENT OF METRICS FOR OPERATOR WORKLOAD
BASED ON THE VISUAL EVOKED RESPONSE

The objective of this program is to assist AAMRL/HEF in an ongoing effort to develop and validate a reliable workload metric using the visual evoked response (VER). The overall goal of BBN's participation in this effort is to seek measurement and analysis techniques that provide measures maximally sensitive to the mental effort expended by a human operator in performing tasks relevant to Air Force operations. Major BBN tasks are to improve methods for data reduction and to conduct descriptive and theoretical modeling of the evoked response.

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An Air National Guard (Tucson) A-7 dual seat aircraft has been fitted with microcomputers which allow the recording of heart rate and respiration rate in-flight. The micros also select 23 variables from the in-flight recorder, multiplex these with the physiological data, and store the multiplexed signal on one audio channel of the HUD TV tape recorder. Data are decoded and analyzed in a computer laboratory at Arizona State University. The pilot flies a set of 12 maneuvers in which Gs, altitude, and airspeed are systematically varied. Since data collection has just begun, no preliminary results can be reported at this time.

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NADC PROGRAMS

NAVAIRDEVCEN has two major programs ongoing at the center. In addition, it supports and sponsors work at other government centers, particularly that at

the Naval Air Test Center. Current NADC programs are focused principally on workload and performance estimation models. These include the Workload Assessment Model (WAM) of the CAFES system and the Human Operator Simulator (HOS) model.

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INDIVIDUAL DIFFERENCES IN TIME-SHARING WITHIN THE FRAMEWORK OF A STRUCTURE SPECIFIC RESOURCES MODEL OF HUMAN INFORMATION PROCESSING

The objectives of the research are:

1. Develop a paper and pencil instrument to assess certain verbal and spatial abilities, and cognitive styles (e.g., field independence) which are considered important in flying.

2. Develop a psychomotor test battery which will test skills specifically related to operational flying and investigate time-sharing skills within the framework of a structure-specific capacity theory of attention.

3. Determine if individuals maintain a consistent relative hierarchy among the structures across different time-sharing situations.

4. Investigate the relationship between specific cognitive abilities and time-sharing mechanisms.

5. Determine which time-sharing performance (i.e., time-sharing within or between the various structures) is the best predictor of complex flight performance in a simulator.

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THE RELATION BETWEEN HUMAN PERFORMANCE AND BIOMEDICAL INDICES IN EVALUATIONS OF POTENTIALLY ADVERSE FACTORS IN THE AVIATION ENVIRONMENT

The purpose of this project is to define the biomedical and performance implications of the kinds of stresses imposed on aviation personnel (e.g., altitude, fatigue, sleep loss, drugs, alcohol, dieting, and medical conditions). This task of the CAMI Aviation Psychology Laboratory (AM-A-81-PSY-85) provides performance measurement support to the Aviation Physiology Laboratory's task AM-A-81-PHY-133. The CAMI computerized Multiple Task Performance Battery (MTPB) is used to assess complex (time-sharing) performance in a synthetic work situation involving the monitoring of light signals and meters, processing of arithmetical information, problem solving, visual

pattern discrimination, and perceptual motor control (two dimensional compensatory tracking). Five subjects can be run simultaneously in this apparatus. Different combinations of tasks are programmed to vary workload. Subjects are typically given 12 hours of practice on the MTPB before experimental testing is begun. Data analyses are based on time and accuracy measures. In addition, a composite index can be computed to reflect the overall quality of performance. Relations between performance and biomedical measures obtained in corollary studies by the Aviation Physiology Laboratory receive special emphasis.

RECENT RESEARCH

Crash Diet Experiment

FAA statistics reveal that the weight of the average civilian airman is 22.7 pounds above the average acceptable weight according to weight/height guidelines, and that the prevalence of obesity is increasing in this group. An experiment was conducted to evaluate the effect on complex performance of one of the more stringent dieting strategies, the crash diet, which involves abstinence from caloric intake for at least 24 hours. Performance testing with the MTPB followed both a 24-hour crash diet and a 24-hour normal diet. During performance testing, 12 male subjects breathed an O_2/N_2 gas mixture equivalent to 12,500 feet, the highest altitude at which continuous flight is permitted without supplementary oxygen. There were no significant effects of crash diet under low workload. Several measurements showed a slight enhancement of performance by crash diet under medium and high workload conditions. Physiological measurements indicated an energy conservation pattern (reduced activity) during the crash diet condition. Although no adverse effects of the crash diet were observed, the possibility should be considered that longer periods of dieting or interactions of mental and physical fatigue with dieting could lead to performance deficit.

Smoking Withdrawal Experiment

A petition to the FAA to prohibit smoking on the flight deck of air carrier aircraft led to an experiment which evaluated the effects of short-term smoking withdrawal on the complex performance of habitual smokers. Seventeen men and women who were habitual smokers performed on the MTPB in two 4-hour intervals in the other session. During testing, subjects breathed an O_2/N_2 gas mixture equivalent to a cabin altitude of 6,500 feet, a common cabin altitude in pressurized air carrier aircraft. When smoking was prohibited, MTPB performance decreased significantly, largely as a function of decrements in tracking. Higher heart rates and higher ratings of attentiveness occurred during the smoking condition and are consistent with the performance data. A cautious approach to the prohibition of smoking during flight by aircrew members is suggested. Milder approaches such as smoking cessation programs were recommended. Future research in this area should concern the effects of longer periods of withdrawal and higher cabin altitudes.

CURRENT RESEARCH

In the current year, data collection has been completed in an experiment concerning the effects on complex performance of the interaction of physical fatigue and altitude. Performance testing occurred in ground level and altitude (12,500 feet) conditions during a 3.5-hour recovery period following strenuous exercise and control treatments. Data analysis is in progress. Data collection is proceeding in a study of the interaction of alcohol effects with altitude. Subsequent experiments will concern the effects of mental fatigue as a function of age and the effect of hangover and altitude on complex performance.

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RECENT EFFORTS IN PLANNING AND DEVELOPING HELICOPTER WORKLOAD METHODOLOGY AND ASSESSMENT

Methodology has been planned and developed for conducting and assessing crew workload (timeliness) and crew coordination (visionics symbology and voice communications) during dedicated two-manned flight operations testing. Parameters have been described for on ground and airborne collection of quantitative data on PCM data watanabe strip charts and MUX data strip plots. Measurement instruments to convert crew attitudes on crew workload and crew coordination to numerical values by scaling techniques have also been investigated.

FUTURE EFFORTS IN APPLYING HELICOPTER MENTAL WORKLOAD METHODOLOGY AND ASSESSMENT

Activities in helicopter workload methodology and assessment for perceptual, meditational, communication, and motor processes are being proposed for the near future.

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APPLICATION OF FUZZY MEASUREMENT THEORY TO WORKLOAD MODELING

Fuzzy measurement provides a logic and calculus for using terms such as "high, low, moderate" to be used instead of numbers, while retaining inference rules based on fuzzy equivalents of AND, OR, implication, etc. We are comparing the use of fuzzy and traditional crisp methods for workload measurement. Results suggest that fuzzy methods are as powerful as crisp measures and can provide additional insight into mechanism. Funded by NASA Ames.

DEVELOPMENT OF HEART-RATE SPECTRAL MEASURES

We are developing Mulder's use of the 0.1 Hz band in the heart rate power spectrum. We have succeeded in applying it to continuous manual control. We are trying to develop an on line real-time digital filter to pick up this component. It interacts with personality and objective attitudes. Funded by NASA Ames.

INDIVIDUAL DIFFERENCES AND SOCIAL FACTORS

We are beginning work on attitudes, personality, and social factors in determining workload. The ideas have been developed particularly by two graduate students in our group, Penelope Sanderson and Craig Thornton.

SKILL-BASED, RULE-BASED, AND KNOWLEDGE-BASED BEHAVIOR AND WORKLOAD

We are using a simulated (video game) surface effect vehicle to investigate the interaction of these three styles of information processing as sources of workload. The task requires well practiced operators to exercise continuous manual control at different levels of difficulty while dealing with more or less demanding procedural rule tasks, and occasionally with problem solving situations for which they have not been trained. Funded by NASA Ames.

ERROR AS A SOURCE OF WORKLOAD

Following some ideas of Sandy Hart, we have done a preliminary experiment in which knowledge of errors changed workload even when it had no effect on the amount of work to be done. Funded by NASA Ames.

In most of our studies (all of them in principle!), we combine physiological, subjective, and performance measures and cross correlate them.

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PERFORMANCE RESEARCH

Our research has not been directly concerned with the assessment of workload or the effects of workload. Rather, the primary thrust of our research has been conducted with the assessment of performance effects of stressful conditions. In this research, we have several levels of workload to produce realistic performance requirements in a synthetic work situation, and to determine the effects of various stresses on performance at the different workload levels. One of the consistent findings has been that the effects of stress on team performance is directly related to the conditions under which the team is performing.

EFFECTS OF TRAINING CONCURRENT TASK STRATEGIES ON THE ACQUISITION AND TRANSFER OF COMPLEX SKILLS

This study investigates the acquisition and transfer of concurrent task skills of different workload requirements through the use of differential training regimens designed to influence what strategies learners adopt. The purposes of the study are to determine the effects on enhancing dual task acquisition and transfer to a multiple task criterion of (1) differential training conditions; (2) changes in training; and (3) interactions between different concurrent task combinations and different training regimens. The design of the study is a six-group split-plot with two phases of training.

During the first phase of training, 60 subjects, in groups of five, will practice mental arithmetic, vigilance, and a group procedural task under single task conditions or changing priority concurrent task conditions. For the concurrent task practice groups, each of the three tasks will be combined with each of the other two tasks. The practice session will be followed by a multiple task transfer session composed of a schedule of rapidly changing task combinations and demands. During the second phase of training, a part of the subjects will be shifted to a new regimen for dual task practice, followed by a second transfer session.

The data from the training and transfer sessions will be analyzed by means of mixed factorial analyses of variance. Both rate of acquisition and asymptotic performance will be tested. It is hypothesized that type of training will have differential effects on acquisition and transfer of concurrent task skills. Attention will be given to the differential effects of type of training for tasks that represent different workloads.

INDIVIDUAL DIFFERENCES IN MULTIPLE TASK PERFORMANCES

Several recent efforts have provided data that contribute to the understanding of individual differences in multiple task performance involving different workload levels. Data from a previous investigation of the effects of continuous work and sleep loss on subject's performance of the Multitask Performance Battery (MTPB) of the synthetic work methodology have been reanalyzed so as to examine (1) the range and consistency of individual differences at different workload levels, (2) individual differences in the acquisition of skill in performing tasks representing different workload levels, and (3) the predictability of individual performance at different workload levels during continuous work and sleep loss. Results of these analyses indicate that there are very large individual differences in response to stress at all workload levels. It was also found that, regardless of workload level during MTPB performance, individual subjects were quite consistent in their response to four exposures to continuous work and sleep loss stress; that is, all measures of performance indicated that poor (or good) performance under the first stress exposure were also poor (or good) performances under the other three exposures. These consistent individual differences also seem to be predictable from individual performances just prior to the stress exposures (correlations across the four exposures and the individual performance measures ranged from .57 to .99). Other analyses have indicated that, within the synthetic work, multiple task situation, different subjects learn a given task at different rates. Furthermore, for a given individual, the rates of skill acquisition are different

for different MTPB tasks; further study is needed in order to determine the extent to which these differences are due to difference in workload produced by the different tasks. Recent analyses indicate that rates of acquisition of performance on the least difficult tasks (watch-keeping) were positively correlated with performance during stress, whereas rates of skill acquisition on the most difficult task (math) were negatively correlated with performance under stress. Additional research is needed to explicate relationship between workload effects and the potential utility of skill-acquisition rates as predictors of performance under stress and in other operational situations.

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PROJECT 1, RESOURCE SPECIFICITY OF COMPONENTS
OF CORTICAL EVOKED POTENTIALS (1980-1983)

In recent theories of mental workload, it is assumed that human workload is a multidimensional construct; that is, the workload of a task is not a scalar quantity but a vector quantity associated with some number of yet to be identified dimensions (e.g., Derrick, 1981). Recent research suggests that components in event related brain potentials can be used in the assessment of allocation of attention (e.g., Wickens, Heffley, Kramer, Donchin, 1980).

Especially the P300 has been proposed as an index of perceptual load on perceptual resources.

The aim of our project is to determine the sensitivity of endogeneous negative and positive components to task variables affecting perceptual, central, and motor mechanism. The following task variables are used:

1. Display Load
2. Memory Load
3. Combinations of Display and Memory Load
4. Stimulus Degradation
5. Training in Consistent versus Varied Mapping Conditions
6. Response Probability
7. Stimulus Response Compatibility

Task variables 1 and 2 are also examined during speed and accuracy regimes.

A computer algorithm has been written which identifies specific components in single trials.

PRELIMINARY RESULTS

An early negative component (N175) is very sensitive to display load but not to memory load. A late positive component (P550) is very sensitive to both memory and display load. Sensitivity is visible both in changes in latency

of amplitude of these components. Response probability also affects the P550 component, but not stimulus response compatibility.

PROJECT 2, TASK RELATED CARDIOVASCULAR STRESS

This project studies the sensitivity of cardiovascular indices to the processing demands of mental tasks. The main dependent variables are power spectrum analysis of heart rate and blood pressure fluctuations, the preejection period, left ventricular ejection time, and pulse transmission time. Discrete mental tasks are used, ranging from search tasks to sentence comprehension tasks to language translation tasks (simultaneous interpretation).

Results indicate that the 0.10 Hz component of the cardiac interval signal, a component related to the frequency response of the baroreceptor reflex, is diminished during tasks which require controlled processing and in which respiratory activity is regular, and increased during tasks which require controlled language processing. In both cases, the homeostatic mechanisms of short-term blood pressure control are highly changed; in the first case, there is a diminished baroreceptor sensitivity; in the latter case, baroreceptor sensitivity is increased. These data, together with other indices, indicate the existence of different required cardiovascular states. Individual profiles indicating reactivity are used as a first step in identifying individuals at risk.

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WORKLOAD AS A FACTOR IN AIR CARRIER INCIDENTS
THAT EXEMPLIFY DEFICIENT RESOURCE MANAGEMENT

A set of 250 commercial aviation incidents exemplifying deficient team functioning in the utilization of available resources was selected from the 7,689 incidents reported to the NASA Aviation Safety Reporting System during the period from 15 April 1976 to 23 May 1978. Each incident was rated as to the extent selection criteria were met. The 84 highest rated exemplars were designated for more comprehensive analysis. Resource management was formally defined as a man-machine system concept. A definition-related schema for incident analysis was developed in which workload was one of the possible categories to which evolutionary and recovery factors were classified. Workload, here used to categorize factors involving problemmatic input load, enabled or contributed to the evolution of 25 of the 84 incidents. In many of these incidents, deficient workload management, involving an inadequate setting of task priorities, was more proximally related to incident evolvement. Details of this study are documented in "Analysis of Eighty-Four Commercial Aviation Incidents: Implications for a Resource Management Approach to Crew Training," by M. R. Murphy, in the Proceeding of the 1980 Annual Reliability and Annual Reliability and Maintainability Symposium, 22-24 January 1980, San Francisco, CA. This analytic effort is being extended to include additional incidents and an in-depth analysis.

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TASK LOAD AND OPERATOR ATTENTION CAPACITY IN TIME-SHARING PERFORMANCE

The goals of this investigation are to provide conceptual framework, develop methodologies, and propose measurement procedures to assess task load and operator attention capacity in the performance of complex tasks.

Consistent with these objectives, a new approach to human performance under time-sharing conditions has been proposed and initially tested. This approach is based on economic concepts and used to derive predictions and discuss possible sources of interference in concurrent performance. Some prevailing concepts such as "difficulty," "resources," "load," and "efficiency" have been formally examined and redefined and new distinctions have been proposed.

To get a complete picture of performance limitations under time-sharing conditions, it is proposed to manipulate task preference as well as difficulty parameters and present their joint effects by families of trade-off functions. This approach was applied to explore the interactions between axes in two dimensional tracking tasks. Additional experiments along these lines are currently being conducted on pairs of tracking and digit classification tasks and angular tracking paired with position tracking.

Two directions of future research are proposed: one represents a continued thrust to identify the nature and sources of limitations of the human processing system. It is accompanied by an effort to develop measures of workload under time-sharing conditions. A second line of studies is proposed to investigate the implications of this research for the development of training procedure and learning processes in the acquisition of time-sharing skills.

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A methodological approach to measuring workload was investigated for evaluation of new concepts in VTOL aircraft displays. Physiological, visual response, and conventional flight performance measures were recorded for landing approaches performed in the NASA Langley Visual Motion Simulator (VMS). Three displays (two computer graphic and a conventional flight director), three crosswind amplitudes, and two motion base conditions (fixed versus moving base) were tested in a factorial design.

Multivariate discriminant functions were formed from flight performance and/or visual response variables to maximize detection of experimental differences. The flight performance variable discriminant showed maximum differentiation between crosswind conditions. The visual response measure

discriminant maximized differences between fixed versus motion base conditions and experimental displays.

Physiological variables were used to attempt to predict the discriminant function values for each subject/condition trail. The weights of the physiological variables in these equations showed agreement with previous studies. High muscle tension, light but irregular breathing patterns, and higher heart rate with low amplitude all produced higher scores on this scale and, thus, represented higher workload levels.

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SUBJECTIVE MENTAL WORKLOAD ASSESSMENT

The objective of this initial project was to develop scales which would quantify important dimensions of subjective cognitive load associated with vessel control in port and harbor (restricted waterway) settings. Several studies related to channel navigation by pilots of large vessels were conducted. Each utilized full-mission, real-time, ship handling simulation to present to licensed pilots a variety of ship handling scenarios which differed in difficulty. Environmental disturbances and visibility restrictions were the principal loading variables. The research led to the development of Pilotage Evaluation Rating Scales (PERS). The PERS contains several scales, including environment, cognitive level, stress, ship handling difficulty, task difficulty and total workload. Each is composed of several nine-point bipolar, dimension descriptors. The scales have been found to be generally sensitive to workload variations, easy to administer, and accepted by pilots.

SENSITIVITY AND INTRUSION OF A VARIETY OF WORKLOAD MEASURES

The objective of this project is to systematically test the sensitivity and intrusiveness (on primary task performed) of a wide variety of workload measures to the cognitive workload associated with ship bridge activities. Several related research questions are being tested including an investigation of the time sensitivity of post hoc secondary measures to when high loadings occur. The project will be broken into seven experiments, each of which evaluates a different combination of workload metrics including: post hoc subjective measures, continuous subjective ratings, physiological measures, secondary task measures, and primary task measures. The primary loading variable will be environmental disturbance, and a second independent variable will dimensionalize ship piloting tasks to provide a range of utilized processing resources. Each study will utilize professional ship pilots to navigate a vessel through a simulated waterway which was especially constructed for the study. Full mission, real time, ship handling simulation will be used. The studies are currently being conducted, hence results have yet to be obtained.

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ANALYSIS OF OPERATOR INPUT LOAD/WORKLOAD DURING ENGINE CONTROL ROOM ACTIVITIES IN NAVY SHIPS

In order to evaluate operator input load during engine control activities in a German Navy ship, a questionnaire has been developed consisting of 18 items. It has been constructed according to the Likert Scaling Method and contains items of perception, central information processing, and response execution as well as items, which are common to all of these stages. The questionnaire may also be applied to other tasks of the process control type and is related to detect deficiencies of the man-machine interface, which should be improved to reduce workload.

In addition, it is also intended to use the questionnaire in comparing and evaluating interface concepts. As work is still in a developmental stage, there are no experimental data about validity.

In a parallel approach, Subjective Workload Assessment Technique (SWAT) is to be used to assess operator workload with engine control room activities. The evaluation results of SWAT are to be compared with the questionnaire data.

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THE EFFECTS OF CERTAIN GIMBAL ORDERS ON TARGET ACQUISITION AND WORKLOAD

Purpose

If air-to-ground imaging sensors are mounted to aircraft by different gimbal order systems, the displayed scene will rotate differently, even though the flight paths are identical. The purpose of this research was to investigate the effects of three gimbal orders (roll-pitch, yaw-pitch, and pitch-yaw) on target detection, recognition, and identification performance and also operator workload.

Method

Videotapes of simulated air-to-ground target runs were presented to 18 experienced pilots. The tapes were made using the Martin Marietta Aerospace Company, Orlando, FL, 40 feet x 40 feet terrain table and the facilities of the Guidance Developmental Center in Orlando. In addition to these target tapes, a random numbers tape which presented random numbers at various rates was used. The subject searched the monitor on which the target scenes were displayed and indicated as early as possible his detection, recognition, and

identification of the target. This was his primary task. He was also instructed to read aloud the random numbers which appeared simultaneously on the adjacent monitor during the target run. This task was to be performed in his "spare" time only, while he accomplished target detection, recognition, and identification as early as possible.

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TEST BATTERY

The purpose of this research project is to develop a test battery of psychological and physiological measures in order to evaluate both the level and type of workload found in a flight deck environment. As the measures are defined and evaluation methods developed, a series of part task simulations will be conducted to determine the utility and sensitivity of the selected measures. Performance measures and time line data will also be collected during the simulations to be correlated with the workload data. All data will be used in the development of a workload assessment computer model for preliminary design evaluation.

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NEUROPHYSIOLOGICAL BASIS OF EVENT RELATED BRAIN POTENTIALS

Event related potentials (ERPs) are useful for evaluating brain function and provide a tool for enhancing the performance of man-machine systems in terms of operational feedback, display design, and personnel selection and training. However, an understanding of the physiological basis of ERPs is required to determine what brain functions are revealed by them. Limitations in human research necessitate the use of animals. A reliable paradigm for studying ERPs in animals is the cued reaction time (RT) task, which involves training subjects to attend to a stimulus cue indicating that a second, significant, stimulus will appear. Performance of the task involves psychological processes such as memory, expectancy, and attention which are associated with complex ERPs, some of which are similar in humans and monkeys. The major goal of the research proposed here is to delineate, in monkeys, the cerebral system involved in the cued RT task. Experiments are designed to determine (1) which regions of the brain exhibit ERPs, (2) the relationship of ERPs to neuronal activity, (3) the similarity of monkey and human ERPs, (4) how intracerebral nuclei interact, and (5) neurotransmitter effects on ERPs. Subsequent experiments will define anatomical and neurochemical pathways involved in ERP genesis.

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PERFORMANCE EVALUATION IN TRAINING SIMULATORS

The purpose of the project is to develop a method for observation and analyses of operator performance, which can provide data on decision making in critical situations. One condition is that the observations must not disturb the normal use of the training simulator, or interfere with the instructor's normal work. This will make it possible to collect data from a large number of highly realistic situations with stress and high mental workload. The observations are based on a detailed description of the expected performance, which is used to detect discrepancies (faults and mistakes in the performance). The analysis is based on the general decision model and performance analysis principles developed at RISO and used in a considerable number of international projects. The results from the pilot test support the usefulness of the approach.

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SUBJECTIVE WORKLOAD ASSESSMENT TECHNIQUE (SWAT)

There are a number of reasons, both theoretical and practical, why any complete workload test battery should include a subjective measurement technique. Also, a need exists for a subjective measure that has been systematically developed and evaluated so that it can be generally applied in various situations. SWAT is being developed as a candidate generalized measure. SWAT is based upon a conceptualization of workload as a multidimensional concept. Three dimensions (time load, mental effort, and psychological stress) are defined. Conjoint measurement is used to define the combination rule used by subjects in ordering descriptors for all possible combinations of levels of the three factors. Conjoint scaling is then used to establish a scale which conforms to the combination rule and maintains the ordinal structure of the original data. The result of this procedure is an interval level workload scale for application to specific events of interest to an investigator.

SWAT-1, a three-level version, is available. Data demonstrating validity and reliability have been obtained.

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EFFECTS OF NEW TECHNOLOGIES IN OFFICE WORK

Thesis

The introduction of new technologies is accompanied by a shift of demands. Demands and workload will change in the areas of:

- Energy
- Information
- Organization
- Equipment
- Work Place
- Environment

The composition of demands must be designated with respect to human possibilities and limitations.

Methods

- Ergonomic Job Description Questionnaire
- Performance Measures
- Physiological Measures (electromyogram, electroculogram, heart rate, arrhythmia).

CLASSIFICATION OF WORKLOAD BY ANALYSIS OF DEMANDS

Thesis

Evaluation workload should be analyzed together with task oriented workloads. Typical combinations of workload factors are to be described to point out areas for further research.

Methods

- Ergonomic Job Description Questionnaire
- Cluster Analysis
- Factor Analysis
- Demand Profiles

REDUCTION OF WORKLOAD BY ERGONOMIC KEYBOARD DESIGN

Thesis

Static and dynamic workload may be reduced through an ergonomic design of keyboards.

Methods

- Performance Measures (lateral/contralateral keying)
- Physiological Measures
- Literature Research

SUPERPOSITION OF CLIMATE AND INFORMATORY WORK

Thesis

Performance and physiological homeostasis vary with climatic and informatory workload. Recovery periods will depend on composition of workload factors.

Methods

- Performance Measures
- Physiological Measures
- Subjective Rating
- Model Development for the Estimation of Recovery Periods

NEW TECHNOLOGIES IN TEXT PROCESSING AND THEIR IMPACT ON MAN (1979-1981)

Abstract

New technologies are classified due to their degree of automation. In field studies, task analysis is conducted in different branches of industry and administration. Tasks are clustered to similar groups for demands. For these groups, data of stress-strain measurements over 8 hours were recorded and assessed. Unfavorable job demands could be isolated and proposals for designs could be given.

ANALYSIS AND DESIGN OF CONTROL TASKS IN A TV STATION (1980-1981)

High job demands (perception, communication, static work, working hours, climate) were isolated for different jobs. Based on physical and electrophysiologic measurements, as well as subjective rating, a new design for the control tasks was proposed.

ERGONOMIC DESIGN OF KEYBOARDS (1979-1981)

Information on keyboard design was collected from literature. Literature was coded and stored in an information and documentation system. Laboratory research on stress reactions due to design parameters led to design proposals for typewriter keyboards.

SUPERPOSITION OF INFORMATORY WORK AND CLIMATIC STRESS (1977-1982)

Performance and strain reactions were recorded during superposition of stress factors. Maximal endurance limits could be determined. Regarding physiologic measures and endurance limits, rest periods can be proposed depending on (1) difficulty of informatory work, (2) climatic stress, and (3) duration of work.

SUPERPOSITION OF INFORMATORY WORK AND VIBRATION (1976-1982)

For crane driving tasks on a simulator and superimposed vibrations, maximal endurance limits are determined. Rest periods regarding performance and strain will be derived. The results will be validated in field studies.

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HEART RATE MEASURES

A pilot's heart rate is monitored routinely during flight trial at Bedford where workload estimation is an important requirement. Results are used primarily to augment a pilot's subjective opinion and to identify rapid or short-term changes in levels of workload. Current flight trials include evaluation of approach aids for Sea Harrier, Category 3 approaches and landings, and head-up display.

A recently introduced rating scale based on the Cooper-Harper Handling Qualities rating scale is being used and ratings from a number of flight tasks compared with heart rate. Early results are encouraging.

Further research into the value of heart rate as a measure of aircraft handling workload is being undertaken on an "opportunity basis." Three different types of high performance aircraft are being compared for workload during approach and landings and during formation flying. Test pilots fly each type and rate the workload for comparison with their heart rates.

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We have no projects in mental workload. However, several of our flight management studies have included mental workload in models and/or measurements. Workload is only one aspect of our overall objectives.

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"BACK-TO-BACK" EXPERIMENTATION AS A TOOL TO ISOLATE MULTIPLE RESOURCES

A view proposed by Sanders (1979) and Navon and Gopher (1979, 1980) states that performance may be based on multiple resources-distinct resource pools

are tied to defined structures or functions of the cognitive system. It is suggested that different stages of processing as derived from additive factor studies could be promising candidates for multiple resources.

One of the main problems involved in isolating different resources by way of a POC-type of resource analysis (see Navon and Gopher, 1979) concerns the many experimental conditions required to obtain reliable POC-functions. It could be of great importance if, prior to a POC analysis, a screening was possible in order to test viable task structures. This may be enabled by the approach proposed by Gopher and Sanders (1984) who tried to converge two conceptual frameworks (theory of processing stages, resource theory) and their pertinent methodologies.

This method of "back-to-back" experimentation involves the clarification of the additive factor stage structures of the experimental tasks as a first step. In a subsequent dual task experiment, two tasks are combined in order to investigate the demand composition of the tasks. In each session of this experiment, a constant concurrent task B is paired with different versions of task A under several dual task priority conditions. From the resulting POCs, it can be inferred whether a single resource or multiple resource polls determine the observed performance.

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SUMMARY OF ONGOING RESEARCH

The major focus of attention for both basic research and exploratory development for the Crew Performance Branch is aimed at developing and applying means to assess the stress, fatigue, and workload effects on crew performance in adverse operational conditions and environments. Both in-house and contract activities are involved. The basic research efforts are performed as a part of the program of the Air Force Office of Scientific Research. The exploratory development activities are being undertaken in concert with the Workload and Ergonomics Branch of the Armstrong Aerospace Medical Research Laboratory, Wright-Patterson Air Force Base, Ohio.

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WORKLOAD DEFINITION

We have been engaged in two general programs in recent times. One has been concerned with the basic philosophical issues of the definition of mental workload as a conceptual schema. Our effort has been directed toward analysis of the modeling requirements for estimation of the load imposed by definable hypothetical system which can be simulated on a computer and operated by a model of the human operator.

COMPARISON OF SECONDARY TASK AND SUBJECTIVE METHODS

At a more pragmatic level, we have been making direct experimental comparisons between secondary task methods and subjective estimations for some simple tasks based on a TV "Pong" game. The general conclusion seems to be that subjective estimation by the operator doing the task is more consistent than the measures obtained by secondary tasks. Since the ultimate validity of any technique is the subjective one, it should be the case that subjective methods will prevail for field work except in cases (labor-management problems, for example) where objective methods are required.

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SUBJECTIVE WORKLOAD ASSESSMENT IN SIMULATED IFR FLIGHT

A cooperative project with Professor R. Simpson under FAA/DOT sponsorship had resulted in the development of a three dimensional workload rating scale. It is now being evaluated in simulation experiments. Several reports have resulted, including a master's thesis by J. Katz.

MENTAL WORKLOAD IN FLIGHT MANAGEMENT

Using an experimental multitask paradigm developed by K. Tulsa in our laboratory several years ago, B. Daryanian has obtained subjective workload ratings for monitoring/control tasks composed of 27 combinations of three parameters: rate at which new tasks are imposed, time available for doing the tasks, and efficiency in doing the tasks. Rate at which new tasks are imposed had high correlation with subjective workload; the other factors had none. This work resulted in B. Daryanian's master's thesis.

BASIC RESEARCH IN HUMAN SUPERVISORY CONTROL

Includes mental workload as key factor in performance of human computer system control. Funded by ONR. Experimental techniques involve on-line computer simulation and computer mediated performance measurement and subjective scaling in a variety of contexts.

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PROJECT I

This project emphasizes quantitative methods for assessing intellective overload. The human transfer function is measured in a psychophysical workload context to determine individual load carrying capacity and intellective load carrying threshold.

PROJECT II

The intellective load placed on the operator of a system is measured to assess areas (in system employment) of operator overload and underload. The results are used to derive areas of needed system redesign/modification.

PROJECT III

The contribution of cognitive stress to intellective overload is assessed along with other variables such as shift length, work-rest cycle, group factors, diurnal rhythm, etc. The result is a measure of anticipated performance degradation due to these factors.

PROJECT IV

A theoretic analysis is being completed to define the properties of cognitive frames needed to reduce the load on the decision maker in the distributed decision making situation. The result will be a list of the properties required in a display situation to convey the information which forms the basis for a decision.

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WORKLOAD MODEL

A paper has been written to present some reflections about the problem of mental load and the measurement of the level of mental load. A general model of the relation between mental control effort and performance is given. Some connotations are made regarding the notion of mental capacity.

The model proposed is suggested to be applicable in the particular man-machine situation of an arm amputeed patient using a prosthesis. Pilot experiments with the aim to develop methods to measure the control effort in using a prosthesis is given as an example of the application of mental load measures.

At the end of this paper, some questions are raised as to the factors which may restrain progress in mental research.

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General Dynamics
Pilot-Vehicle Interface IRAD, Avionics Department
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Mail Zone 1766
Fort Worth, TX 76101
Phone: (817) 732-4811, Ext. 4515

BIOCYBERNETICS

Objectives for this project focus on study and evaluation of brain electrical activity (both transient and steady-state responses) for use as metrics in workload assessment and for rudimentary hands-off display quality optimization. For the first objective, sensitivity of the brain evoked responses to sensory and cognitive parameters, especially reflected in amplitude and phase changes, will be analyzed to determine usefulness of the measures as aids in display design and subsystem evaluation. Alerting and warning systems will receive emphasis; discrete presentation of the warnings will provide stimuli for transient evoked responses to determine how the information is utilized by the pilot (i.e., whether it is acknowledged, ignored, processing characteristics, etc.). Analysis of the sensory, cognitive, and motor parameters of the alerting and warning information systems will be conducted to determine which combinations of parameters effect optimal utilization of the displayed information. The purpose of this investigation is to validate the psychophysiological measurement techniques in other than a laboratory environment and to compile a design guide matrix which will enable the technique to be used during the design process.

The second objective focuses on the steady-state response. Steady-state brain electrical activity, evoked through sinusoidal modulation of display intensity, will be used for on-line monitoring of display image quality (intensity, contrast, etc.). In addition, an automatic feedback control system will be developed which will alter display image qualities based on evoked response characteristics.

PROJECT DESCRIPTIONS

Pilot-Vehicle Interface Independent R&D (IRAD)

Current objectives for this project focus on the study and evaluation of brain electrical activity for use as a metric in workload assessment. Sensitivity of transient brain evoked responses to discrete events (emphasizing alerting and warning systems) will be analyzed to determine usefulness of this measure as an aid to workload assessment and subsystems design evaluation. The purpose for this investigation is to validate psychophysiological measurement techniques in other than a laboratory environment. Investigations into the perceptibility of synthesized speech will also be made utilizing brain evoked potentials. Another objective involves the development of quantifiable performance assessment methodology utilizing behavioral data.

Neuropsychological Workload Test Battery Validation Study

The objective for this project is to validate neuropsychological workload assessment methodology in a nonlaboratory environment. The battery to be validated includes neuropsychological/physiological tests of the following: auditory/visual rare event monitoring, heart rate variability, the steady-state evoked response, EMG analysis, the auditory/visual Sternberg paradigm, brainstem, eyeblink analyses, and artificial tracking tasks. The test environment will consist of seven distinct simulated operational environments (fighter/bomber aircraft). Methodology for assessing types/levels of workload is also being investigated.

TOLE, JOHN R.
Worcester Polytechnic Institute
Biomedical Engineering
Institute Road
Worcester, MA 06109
Phone: (617) 793-5617

QUALIFICATION OF PILOT WORKLOAD VIA INSTRUMENT SCAN

The following describes work in progress on the use of visual scanning behavior as an indicator of pilot workload. The study is investigating the relationship between levels of performance on a piloting task, the skill of the pilot, the level of mental workload induced by an additional verbal task imposed on the basic control task, and visual scanning behavior. The basic control task involved maintaining a general aviation flight simulator on a straight and level constant sensitivity, instrument landing system (ILS) course with a low level of turbulence. A task employing an algorithm based on relative magnitudes of a sequence of numbers was used to increment the subject's mental workload. The level of loading for various conditions was also estimated in an independent series of runs using a side task. The subject's lookpoint on the instrument panel during each 10-minute run was computed via a TV oculometer and stored. A total of 13 pilots of varying skill participated in two sets of experiments.

The results indicate an increase in fixation dwell times, especially on the primary instrument, with increased mental loading task. The amount of "starting" observed appears to depend on the level of skill of the pilot; skilled subjects appear to stare less under increased loading than do novice pilots. Sequences of instrument fixations were also examined. The percentage occurrence of the subject's most used sequences decreased with increased task difficulty for novice subjects but not for highly skilled subjects.

Analysis of the periodicity of the subject's instrument scan was accomplished using auto correlation. Skilled pilots were found to scan their primary instrument in a periodic fashion. The period was related to the interval between number task presentation. A similar result was not observed in novice pilots. This finding suggests that skilled pilots may handle the additional loading task in a much more systematic fashion than do novice pilots.

Entropy rate (bits/sec) of the sequence of fixations was also used to quantify the scan pattern. It consistently decreased for most subjects over the

four loading levels used. An exponential equation in task difficulty was found to be a good predictor of entropy rate. When solved for task difficulty, the equation provided an estimate of the level of task difficulty perceived by a subject. This estimate was used to quantify the workload of the subject.

Piloting and number task performance measures were recorded and a combined performance measure was computed. This was used in developing a model relating performance, skill, and mental workload. Entropy rate of the scan was used to quantify the workload, and skill was estimated independently via a method based on pilot experience. The resulting exponential model fit the data well enough to suggest that this approach has promise in the evaluation of interactions among these variables.

WICKENS, CHRISTOPHER D.
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University of Illinois
Champaign, IL 61820
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TASK INTEGRATION AND WORKLOAD ASSESSMENT: APPLICATIONS OF A STRUCTURE-SPECIFIC RESOURCES MODEL OF HUMAN INFORMATION PROCESSING

This is a programmatic effort to relate theoretical models of attention to measures of task workload, and guidelines for integrating tasks in complex environment. The model we adopt (and are validating) is a multiple resource model that assumes attention is not scalar but a vector quantity where dimensionality is defined by two stages of processing, two codes of processing (verbal versus spatial), and by processing modalities. With regard to workload, we ask how task demands imposed upon the various attentional resources in combination concatonate to generate single scalar measures of workload (subjective ratings, heart rate variability, primary task performance); and how measures of single task workload predict task performance in combination. With regard to task integration, we demonstrate how options in task design that utilize separate resources (e.g., spatial coding, auditory displays, and speech output) can improve the efficiency of dual task performance.

THE EVENT RELATED BRAIN POTENTIAL AS AN INDEX OF ATTENTION ALLOCATION AND TASK RISK

This effort focuses on the unique information that the event related brain potential can provide concerning (1) the locus of processing demands of a concurrent task within a multiple resource conception, (2) the allocation of attention to events in complex auditory and visual displays. The term "unique" stresses the extent to which information derived from the ERP is unavailable from conventional manual and vocal responses. This is a part of a longer programmatic effort by the Cognitive Psychophysiology Laboratory concerning the contributions of the ERP to advances in human engineering. Research support has been provided by ARPA, Air Force AAMRL, and OSR.

DISSOCIATION EFFECTS/SECONDARY STERNBERG TASKS

At Illinois, we are continuing our efforts to compare behavioral (Sternberg task) and physiological (event related potential and sinus arryhthmia) workload measures with each other, and with subjective workload estimates in a variety of settings. One issue focuses on the dissociation between subjective measures and secondary task measures (i.e., what does it mean when two conditions are discriminated by one measure but not by the other). We observe such dissociation when we compare workload changes induced by adding more tasks and by increasing the difficulty of a single task.

A second issue concerns the exploration of the Sternberg task as a secondary task workload index. We are interested in the information provided by slope and intercept measures of the Sternberg RT function and the way in which these related to "central processing," input and output load. In particular, we have examined several applications of this task to flight workload and noted the prevalence of decreasing slopes with additional task workload. This somewhat counterintuitive result, we believe, may be a consequence of (1) the input/output modality of the task employed (auditory/vocal versus task visual/manual), and (2) the mismatch between a primarily spatial flight task, and a verbal languaged based Sternberg task (letter search). As a consequence, we are exploring an auditory spatial variant of the Sternberg task used in the context of various maneuvers on the GAT-2 general aviation simulator.

THE STERNBERG TASK AND THE PILOT WORKLOAD

We have continued to perform a series of investigations using the Sternberg Memory Search Task as a loading and secondary task in simulated aircraft flight. Our interests have focused on the effects of such variables as phase of flight, turbulence, and toxic drugs on both the "slope" and the "intercept" of the Sternberg memory search function. In the process, we are identifying the limitations as well as the strengths of this secondary task measure. Particular interest has focused on a recurring phenomenon in which the Sternberg slope is reduced rather than increased under high load conditions (Christopher D. Wickens).

THE DISSOCIATION BETWEEN SUBJECTIVE WORKLOAD MEASURES AND PERFORMANCE

This project involved an effort to identify generic (i.e., context free) factors that would influence subjective ratings of mental workload and not performance, or the converse. Using a series of different tasks, we have determined that performance is relatively more influenced than subjective workload by the difficulty of a single task, while subjective workload is relatively more affected than performance by the number of concurrently performed tasks. Subjective workload, furthermore, does not discriminate between whether those tasks use common or separate resources, while performance is improved in the latter case. Finally, task characteristics that induce more resource investment will improve performance while also increasing subjective workload (Yei-Yu Yeh: Co-investigator).

P300 AS A PRIMARY AND SECONDARY TASK WORKLOAD MEASURE

We have continued to evaluate the manner in which the P300 component of the event related brain potential can index the residual perceptual/cognitive resources available from a primary task. Conversely, our studies have shown that the P300 elicited by discrete events embedded in the primary task can provide a direct index of the resources invested into a primary task, that is, an unobtrusive primary task measure of workload. We have examined primary task ERPs in the context of a series of step tracking experiments and validated the reciprocity of resources between primary and secondary tasks (Art Kramer and Emanuel Donchin, Co-investigators).

WILSON, GLENN F.
AAMRL/HEG
Wright-Patterson AFB, OH 45433
Phone: (513) 255-2252

STEADY-STATE EVOKED RESPONSE

Steady-state evoked responses (ER) are being tested as to their utility as a measure of mental workload. Several cognitive and motor tasks are being used which each have two or three levels of difficulty. ER measures of phase lag and amplitude recovered during the time subjects engage the various tasks are correlated with the level of difficulty. High frequency (40 to 60 Hz) flicker is being used to elicit the ERs; these have the advantage of being close to fusion frequency and thereby relatively unobtrusive into the primary task.

TRANSIENT EVOKED RESPONSE

Transient evoked responses are being used to assess pilots' responses to emergency situations in a motion based simulator. Single trial evoked responses in response to auditory tones are used to determine whether or not the pilot recognized the onset of the emergency situation in time to take corrective actions. Eye movement analysis is also being used to study point-of-regard during these episodes.

Section 5

WORKLOAD LABORATORIES

This section is a listing of laboratories and research groups engaged in programmatic research on mental workload. The entries are arranged alphabetically by laboratory name. A mailing address is provided, and the laboratory director as well as other personnel are identified. In addition, entries may include a brief description of the laboratory's research interests and goals.

AAMRL WORKLOAD AND ERGONOMICS BRANCH

AAMRL/HEG
Wright-Patterson AFB, OH 45433

Mr. Gary B. Reid, Mr. William Pearson,

Dr. G. Wilson

The lab is dedicated to developing and implementing workload assessment techniques for specific application to Air Force systems. Separate laboratories are involved in development of behavioral/performance measures and neuropsychological/physiological measures. The laboratory mandate involves conducting studies in-house, contractual efforts, and validation studies in simulators and field units. In addition, workload standards for all Air Force systems will be generated, and MIL-Specs for acceptable workload will be produced by CY85.

AIR FORCE SCHOOL OF AEROSPACE MEDICINE

Clinical Sciences Division
Brooks AFB, TX 78235

Bryce O. Hartman

The laboratory has three objectives: identify the top 20 percent of operational aircrew pool, train each to the 99th percentile level, and develop technology base for biologically based cockpit design.

APPLIED PSYCHOLOGICAL SERVICES

404 East Lancaster Avenue
Wayne, PA 19087

Arthur I. Siegel

P. Federman, R. Leahy, M. Pfeiffer, F. Kopstein, and N. Madden

The work emphasizes methods for measuring intellective load and assessing the effects of overload on performance. A factorial approach is taken.

BAC CREW SYSTEMS (2-3755)

P.O. Box 3999, M.S. 82-87
Seattle, WA 98124

Mr. W. U. Hebenstreit

Dieter W. Jahns, Judi Qualy, George Boucek, and Charles A. Anderson

Develop workload assessment/prediction methodology for commercial and military aircraft operability certification. Investigate the utility and sensitivity of various human performance and physiological parameters for scaling operator workload in realistic crew/aircraft/mission contexts. Both analytical and crew-in-the-loop simulation techniques are used.

CENTER FOR WORK SAFETY AND HUMAN ENGINEERING

Industrial and Management Engineering
Technion, Haifa, Israel

Dr. Daniel Gopher

Dr. David Navon and Dr. Peretz Lavic

CENTER FOR APPLIED PSYCHOLOGICAL STUDIES

Old Dominion University
Norfolk, VA 23508

Dr. Ben B. Morgan, Jr.

Dr. Glynn D. Coates, Mr. Peter S. Winne,
Mr. Michael Secunda, and Dr. Raymond H. Kirby

Conduct research dealing with the assessment and enhancement of human performance in man-machine systems. These efforts are directed generally toward improving systems efficiency by increasing the understanding of basic capabilities of the human component in the system and the factors--including workload--that influence these capabilities. We are particularly concerned with the effects of temporal, biological, and environmental stressors on human performance individual differences in performance capabilities and responses to stress and complex skill acquisition, retention, and maintenance. Much of our research is conducted with the multiple task methodology of the synthetic work approach to performance assessment. This methodology routinely involves the assessment of performance at different levels of workload.

COGNITIVE WORKLOAD GROUP

Computer Aided Operation Research Facility
National Maritime Research Center
USMMA, Samuels Hall
Steamboat Road
Kings Point, NY 11024

John M. O'Hara

William Brown

The workload research program's goal is to develop and validate a set of workload measures which are sensitive to cognitive loading associated with large vessel control and navigation activities. Related objectives include the determination of (1) the relation between workload and system performed and (2) the relation between skill level, training, and workload.

CREWSTATION DESIGN FACILITY

ASD/ENECH
Wright-Patterson AFB, OH 45433

Richard Geiselhart

Larry Ivey, Larry A. Carr, William Kalman

The Crewstation Design Facility is equipped with three full flight simulators: an A-10, a FB-111, and a KC-135. The simulators are used to conduct applied human factors research in support of various system program offices (SPOs) at Wright-Patterson. The research problems cover a wide range of topics such as crewstation layout, control/display design, automation, terrain following, air-to-ground attack, display symbology, etc. Although the facility is not dedicated to developing new workload measurement techniques, workload is almost always a major concern in the research efforts. The facility personnel are continuously applying different workload measurement techniques in the various research projects.

CREW SYSTEMS ENGINEERING GROUP

AFWAL/FIGR
Wright-Patterson AFB, OH 45433

Richard Moss

Larry C. Butterbaugh, Evelyn Blanch, and Lt. Dan Basehore

The Crew Systems Engineering Group has the objective of providing crewstation design guidelines and preliminary crew procedures for candidate aircraft. This technology includes developing a physical representation of the cockpit design to include control display formats and workspace layout. The mission scenario is analyzed in terms of necessary systems and associated crew tasks, and these are systematically arranged over time to provide an accurate task time line with which to evaluate the design

effort. Designs are iterated and evaluated with increasing fidelity from mock-up through dynamic pilot-in-the-loop simulation. The process carries through to establishing the technology trade-offs between crew size/workload and avionics automation/sophistication. The Group is also responsible for such functional areas as crew workload measurement and problem analysis for current as well as future aircraft and major systems.

CREW PERFORMANCE LABORATORY

USAF School of Aerospace Medicine
Brooks AFB, TX 78235

Sam Schiflett

James Miller, William Storm, Patrick Dowd

COCKPIT INFORMATION SYSTEMS - WORKLOAD ASSESSMENT

NASA Ames Research Center
Mail Stop 239-2
Moffett Field, CA 94035

Sandra G. Hart

Kathleen Bird, Laura Lapp, Mike Bortolucci,
David Suzuki, and Cheryl Chapel

The global purpose is to develop a methodology for measuring pilot workload in simulation and in-flight research. The immediate aim is to develop subjective rating scales, primary performance measures, and possibly unobtrusive secondary measures, to use in evaluating the impact of cockpit displays of traffic information on pilot and controller workload. In providing these measures, theoretical research will be supported, and more general applications will be developed. The hope is that by stepping back, redefining the problem, and starting back with the pilot and looking at what he does, thinks, and feels and relating this to what he says (and what we measure) about his workload, we can make some headway. Simply trying more secondary tasks or wiring up subjects for more physiological output is not the solution. The reason that the different subjective, objective, and physiological measures correlate with each other so poorly is that each one most likely taps a different aspect of the subjective experience of workload (some focusing on task demands, some on performance, some on stress and physical effort, some on perception, others on cognition, etc.) and most rely on the task requirements as a definition of load and performance as a definition of effort. Neither may be correct or valid.

CYBERLAB

Department of EE and CS
University of Connecticut
Box U-157
Storrs, CT 06268

Professor D. L. Kleinman

Professor Arye R. Ephrath

CYBERLAB was established in 1976 to provide an administrative and academic framework for the conduct of specialized theoretic and empirical research in the field of systems in general and, in particular, systems that include humans as components. The laboratory conducts analytical and experimental research on human performance in manual control and decision making tasks.

DUNLAP AND ASSOCIATES, INC.

920 Kline Street, Suite 203
La Jolla, CA 92037

Clyde A. Brictson, Ph.D.

Anthony P. Ciavarelli, M.A.

EEG SYSTEMS LABORATORY

1855 Folsom Street
San Francisco, CA 94103

Alan S. Gevins

Joseph Doyle, Gerald Zeitlin, Steve Bressler,
Nelson Morgan, Brian Cutillo, John Simmons

The EEG Systems Laboratory performs basic research on measuring human neurocognitive functions. The emphasis is on developing and applying advanced methods of digital signal processing and statistical pattern recognition analyses to up to 64 channels of electrical field data recorded from persons performing highly controlled laboratory tasks. (Multichannel magnetic field recordings are also analyzed.)

The staff consists of interdisciplinary scientists and engineers with specialties in neurophysiology, cognitive science, neuropsychiatry, biophysics, electrical engineering, and computer science.

Current research is concerned with measuring neurocognitive patterns associated with maximal attention, short term memory, perceptomotor coordination, and auditory versus visual processing of numeric information. Another project is concerned with measuring (and predicting) performance decrement consequent to operational fatigue in Air Force fighter test pilots.

EXPERIMENTAL PSYCHOLOGY DEPARTMENT

Bolt Beranek and Newman, Inc.
10 Moulton Street
Cambridge, MA 02238

Dr. Richard W. Pew

William H. Levison, Carl Feehrer, Marilyn Adams

ENGINEERING-PSYCHOLOGY LABORATORY

Department of Psychology
University of Illinois
Champaign, IL 61802

Christopher D. Wickens

William Derrick, John Micilizi, Diane Sandry, and Roger March

The Engineering-Psychology Laboratory is an interdisciplinary facility operated jointly by the Department of Psychology and Mechanical/Industrial Engineering. The laboratory contains a GAT-2 general aviation simulator and three general purpose experimental computers, along with speech recognition and synthesis devices. It is devoted to research in basic issues of human performance, particularly as these pertain to aviation. Primary research activities relate to workload, divided attention, failure detection, and fault diagnosis.

ERGOMETRICS TECHNOLOGY, INC.

4401 Dayton-Xenia Road
Dayton, OH 45432

FAA CIVIL AEROMEDICAL INSTITUTE, AVIATION PSYCHOLOGY LABORATORY, HUMAN PERFORMANCE UNIT

FAA-CAMI, AAC-118
P.O. Box 25082
Oklahoma City, OK 73125

Henry W. Mertens, Ph.D.

Nelda J. Sapp

HUMAN FACTORS GROUP

Department of Industrial Engineering
University of Toronto
Toronto, Ontario
Canada M5SIA4

Neville P. Moray

Neville Moray, Penelope Sanderson, Craig Thornton, Kim Vincente

The department is working on (1) the application of fuzzy measurement to workload; (2) the reliability of the 0.1 Hz component of the heart rate power spectrum; (3) individual differences as modulators of workload; (4) "skill based," "rule based," and "knowledge based" origins of workload; (5) the role of errors in causing workload; (6) closed loop modeling of workload (sponsor NASA Ames).

HUMAN FACTORS LABORATORY

University of South Dakota
Vermillion, SD 57069

J. Stone

Scaling mental workload using category versus ratio scaling techniques.

HUMAN FACTORS TEST AND EVALUATION METHODOLOGY DEVELOPMENT LABORATORY

Naval Air Test Center
Mail Code SY721
Patuxent River, MD 20670

Dr. Carole Bohn, CDR Harv Gregoire, Ph.D., Mr. Dick Walchli,
Mr. Art Weaver, Mr. Gave Intano, Mr. Keith Karn, and Mr. Gary Loikith

HUMAN PERFORMANCE LABORATORY

Engineering-Psychology Department
McDonnell Douglas Corporation
St. Louis, MO 63166

Dr. Larry R. Beideman, Dr. William Cody, and Dr. Kirmach Natani

INSTITUT FUR ARBEITSWISSENCHAFT

Petersenstr. 30
6100 Darmstadt
Federal Republic of Germany

Professor Dr. Ing. W. Rohmert

Dr. E. Haider, Dipl. Ing. R. Helbig, and Dr. P. Jenik

Basic research is done to validate physiological measures or to concentrate on isolated workload factors.

INSTITUTE FOR EXPERIMENTAL PSYCHOLOGY

Kerklaan 30, Haren
The Netherlands, G751NN

Dr. G. Mulder

Dr. L. S. Mulder, Dts. R.A. Brookhuis, Dts. H. Veldman, D.T.S. Bakker

The primary task of the Institute is to train students in Experimental Psychology. The research lines of the Institute are:

1. Research in Cognitive Skills

2. Psychophysiology of Mental Tasks

3. Applied Research (Psychological and Physiological Aspects of Driving; Psychopharmacology)

MAN-MACHINE SYSTEMS GROUP

Electronics Department
RISO National Laboratory
DK-4000 Roskilde
Denmark

Jens Rasmussen (plus five coworkers)

INTRODUCTION

This group is concerned with design and operational problems with safety and reliability in modern process plant. These have to do particularly with the distribution of tasks related to system protection between operations personnel and the plant instrumentation and control system as well as establishing means for including the human in systematic reliability and risk analyses.

MAN-MACHINE SYSTEMS LAB

Room 1-110 MIT
Cambridge, MA 02139

Professor T. B. Sheridan

R. W. Simpson, W. Wood, and J. Tzelgov

Academic research laboratory staffed by graduate students, visiting scientists, and faculty. Devoted to experiments and modeling of man-machine interaction in ocean systems, robotics, nuclear power, and process control.

MENTAL PROCESSES LABORATORY/PSYCHOPHYSIOLOGY LAB--EEG/EDG

Human Factors Engineering
Douglas Aircraft Company
C1-253, Code 35-36
3855 Lakewood Boulevard
Long Beach, CA 90846

Richard F. Gabriel, Ph.D.

Robert T. White, Ph.D. and Michael A. Biferno, Ph.D.

The Mental Processes Laboratory is dedicated to research on mental workload. Of particular interest are the identification of mental processes that contribute most to cockpit workload; the quantification and measurement of mental workload components; and the development of guidelines and criteria for the design of information displays that will minimize mental workload. The laboratory is directed and staffed by the Human Factors Engineering group. In addition to ongoing research, the laboratory investigates specific mental workload problems referred by design groups and constantly endeavors to bridge the gap between basic and applied research. Both behavioral and physiological measures are being investigated.

MENTAL WORKLOAD LABORATORY RWTH AACHEN

Institute for Psychology
Jagerstr, Zwischen 17 und 19
D-51 Aachen
Federal Republic of Germany

Andries F. Sanders

Hans W. Schroiff

MRC APPLIED PSYCHOLOGY UNIT

15 Chaucer Road
Cambridge CB22EF, England

Dr. I. D. Brown

Dr. D. G. Wastell and Dr. P. McLeod

Theoretical and applied research on normal human characteristics and performance, in order to advise governmental and other organizations on the design of work, tasks, and equipment.

NASA LANGLEY RESEARCH CENTER

Flight Dynamics and Control Division
Hampton, VA 23665

Randall L. Harris, Sr.

Dr. Alan Pope, Amos Spadey, and Marvin Waller

Primary interest is to apply oculometer type data and pilot screening data with the pilot's screening data analysis technique to evaluate mental workload. Derived measures from information theory, called Entropy Rate, is also being used to validate these measured for mental workload. Currently one of the projects that is being used to helping this evaluation is a comparison of a Vertical Speed Indicator (versus the conventional dial type VSI).

NAVAL AIR TEST CENTER

Aircrew Systems Department
Patuxent River, MD 20670

NAVAL BIODYNAMICS LAB

Box 29407
New Orleans, LA 70189

Dr. Channing L. Ewing

Drs. Thomas, Guignard, Ewing, Kennedy, Shannon, Bittner, and Carter

The effects of inertial forces on human responses. Inertial forces on all linear angular acceleration. Human response--everything from skeletal to thinking and decision making.

OPERATIONS TRAINING DIVISION

AFHRL/OT
Williams AFB, AZ 85224

Dr. Elizabeth Martin

PERFORMANCE ASSESSMENT LABORATORY

Old Dominion University
Norfolk, VA 23508

Dr. Ben B. Morgan, Jr.

Dr. Glynn D. Coates, Dr. Raymond M. Kirby, and Mr. Peter S. Winne

The Performance Assessment Laboratory conducts research dealing with the assessment and enhancement of human performance in man-machine systems, particularly in industrial and military settings. Falling broadly within the domain of Human Factors and Engineering Psychology, these efforts are directed toward improving systems efficiency by increasing the understanding of basic capabilities of the human component in the system and the factors that influence these capabilities.

Illustrative Problem Areas:

- Effects of temporal, biological, and environmental stressors on human performance.
- Synthetic work methodology in performance assessment.
- Psychomotor, perceptual, and information-processing capabilities of the human operator.
- Individual differences in performance capabilities and responses to stressors.
- Performance effects of circadian rhythms and menstrual cycles. Effectiveness of team training techniques.
- Skill acquisition and maintenance.

PILOT-VEHICLE INTERFACE IRAD, AVIONICS DEPARTMENT

General Dynamics, Fort Worth Division
P.O. Box 748, M.Z. 1766
Fort Worth, TX 76101

June E. Lay

Thomas M. Helfer

Interests of Workload/Lab Group: The pilot-vehicle interface research effort primarily involves the study and evaluation of physiological metrics for assessment of workload and quality of audio/visual stimuli in the cockpit. Physiological metrics of special interest include brain evoked responses and eye blink parameters. The development of quantifiable performance assessment methodology utilizing behavioral data is another objective of this research group.

PSYCHOLOGY DIVISION, INSTITUTE FOR PERCEPTION

Institute for Perception
TNO Soerterberg, The Netherlands

Professor Dr. A. E. Sanders

Dr. A. W. K. Gaillard, Dr. P. Jorna, and Dr. W. H. Janssen

Interest in simultaneous performance of more than one task. Interest in electrophysiological measures of mental load. Both interests are materialized in basic laboratory tests as well as in applied settings like diving and automobile driving.

PTI-UNIT, UNIVERSITY OF STOCKHOLM

Box 5602, S114 86
Stockholm, Sweden

Gunnar Borg

The general interest of the group concerns theories and methods in scaling subjective effort and difficulty. Performance measures of the same variables and their physiological correlates. The theoretical and methodology interest is then combined with various applications in medicine, preventive activities, and rehabilitation in industries and in sports. New psychophysical methods are developed especially for quantitative evaluations of subjective intensity but also for qualitative aspects and dimension analysis.

RAF INSTITUTE OF AVIATION MEDICINE

Farnborough, Hampshire
United Kingdom GU14 6SZ

V. David Hopkin

R. M. Raylor, A. McClumpha, J. V. Berman, and C. S. Narborough-Hall

The psychologists in the General Psychology Section of the Royal Air Force Institute of Aviation Medicine are concerned with their application of practical human factors knowledge, obtained from the literature and from their own research, to solve aviation problems in the air and on the ground. A current interest is the relationship between recent developments in cognitive psychology and practical problems, particularly of information processing, attention, memory, mental workload, and capacity. Human capabilities and limitations are related in task objectives, the physical environment in which the task has to be done, the standards to be achieved, the selection and training required, and technological developments. Current topics of interest include air traffic control systems, aviation maps, cockpit ergonomics, the effects on cognitive processing of minor departures from optimum physical environments, the etiology of errors, and the roles of man in

highly automated systems. Although many practical problems require a short-term answer, longer term studies which give continuity to the work are also conducted.

SYSTEMS RESEARCH LABORATORIES, INC. (SRL)

Human Factors Engineering Division
2800 Indian Ripple Road
Dayton, OH 45440

Mr. Dan Sauer

Dr. William Perez, Ms. Karen Peio, Mr. J. C. Simons, Mr. Ron Spicuzza

SRL is active in all three major areas of workload assessment behavioral, physiological, and subjective. Staff experience includes a broad range of Army, Air Force, and Navy projects requiring workload assessment in applied settings as well as the development of workload metrics in both the field and the laboratory. SRL engineers and programmers design and build many types of systems for physiological recordings, presentations of primary and secondary tasks, and recording of human operator performance data.

The objectives are of two parts: (1) the development of usable, easily implemented, workload metrics for real-world applications, (2) the development and construction of all necessary hardware and software for applying the metrics.

SYSTEMS TECHNOLOGY, INC.

13766 South Hawthorne Boulevard
Hawthorne, CA 90402

Henry R. Jex

D. T. McRuer, I. L. Ashkenas, R. W. Allen, W. F. Clements, R. K. Heffley, R. A. Peters, and W. F. Jewell

Operator control strategy, workload, and human error measurement by instrusive and noninstrusive methods.

INTRUSIVE APPROACHES

Cross adaptive task measure of excess control capacity based on cross coupled instability using existing inputs/describing function analysis by finite fourier transformation using injected test inputs; eye point of regard.

NONINTRUSIVE APPROACHES

Samples data correlation in time domain or phase plane using least squares criterion with existing inputs and eye point of regard.

CONTROL STRATEGY MODELS

Metacontroller based on successive organization of perception (SOP) theory, including isomorphic models for compensatory, pursuit, and precognitive strategies and algorithmic models for the SOP and monitoring processes.

PERCEPTUAL MOTOR WORKLOAD MODELS

Excess control capacity, properties of describing functions, remnant, eye point of regard distributions.

USAF SCHOOL OF AEROSPACE MEDICINE

Crew Performance Laboratory
Crew Technology Division
Brooks AFB, TX 78235

Sam G. Schiflett

James C. Miller

Psychophysiological correlates of sustained attention to complex tasks and psychophysiological analysis of cockpit workload performance. Development and evaluation of performance assessment batteries. Team performance effectiveness measures. Embedded secondary tasks methodology. In-flight capabilities using excess control capacity (CCIT) and Sternberg task. Command and control workload evaluation methodology.

USARTL AEROMECHANICS LABORATORY, FLIGHT CONTROL DIVISION, HUMAN FACTORS GROUP

Director
US Army Aeromechanics Laboratory
DAVDL-AL-C
207-5 Ames Research Center
Moffett Field, CA 94035

David Key

The Aeromechanics Laboratory sponsors a man-machine integration research activity jointly with the NASA Ames Research Center's Helicopter/VTOL Human Factors Office. Applied research on helicopter man-machine integration topics focuses on improved system design methods, concepts, and evaluations. The main areas of effort are helicopter pilot workload and performance, research flight simulation methods and requirements, helicopter control, and display technology.

VEHICLE SIMULATION LABORATORY

155 Whittemore Hall
VPI and SU
Blacksburg, VA 24061

Walter W. Wierwille

Sidney Connor, John G. Casali, and Mans Rahimi

The general thrust of our present workload research is in experimental validation of a variety of workload estimation techniques. Vehicular environments are simulated and techniques are then examined. We are also working on refined rating scales and methods for examining short-term workload.

WORKLOAD RESEARCH GROUP

Decisions and Designs, Inc.
Suite 600, 8400 Westpark Drive
Mclean, VA 22101

John F. Patteron, Ph.D., Michael F. O'Connor, Ph.D., and
Clinton W. Kelly, Ph.D.

To understand, measure, and predict mental and/or physical workload as a function of the characteristics of various types of tasks and man-machine interfaces. Emphasis is on applied as opposed to basic research; mental as opposed to physical workload; subjective as opposed to performance measures. Metric development and scaling are emphasized as part of the development of analytical workload estimation techniques. Primary applications to date have dealt with Naval aircraft, submarines, and other weapons systems. A key concept focusing the group's activities has been system effective operability, which is viewed as a function of task criticality, workload, and system technical effectiveness.

WORKLOAD RESEARCH GROUP

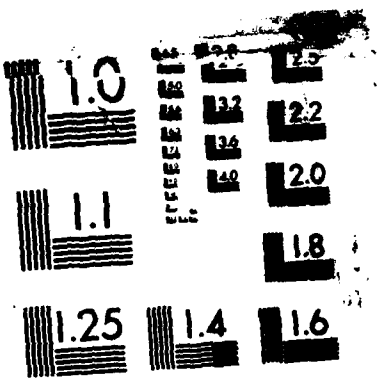
23766 South Hawthorne Boulevard
Hawthorne, CA 90402

Mr. Henry R. Jex

R. Wade Allen, James C. Smith, Warren A. Clement, Anthony C. Stein,
and Richard A. Peters

One or more members of this group, with assistance from various staff members, act as team leaders/members on basic and applied workload measurement projects. Members are two-thirds engineers and one-third engineer-psychologists. Interests cover experimental methodology, model development/validation, device development (e.g., the well known S.T.I Critical Instability Task) and application to man-machine problems (e.g., displays, controls, drugs--the effects of environmental, task, and operator variables on workload).

AD-A168 210 REGISTER OF RESEARCH IN PROGRESS ON MENTAL WORKLOAD(U) 2/2
HARRY G ARMSTRONG AEROSPACE MEDICAL RESEARCH LAB
WRIGHT-PATTERSON AFB OH T R METZLER FEB 86
UNCLASSIFIED AAMRL-TR-86-007 F/G 5/8 NL



Section 6

POTENTIAL FUNDING SOURCES

This section was compiled from responses to a request for the names and addresses of organizations which have interests in mental workload problems and which may be sources of funding for relevant research. It should be noted that these entries reflect the opinions of the respondents and were not necessarily obtained after consultation with a listed organization. Therefore, it is suggested that these entries be used only as a general guide to initiating inquiries about research funding.

UNITED STATES

Armstrong Aerospace Medical Research Laboratory
Wright-Patterson AFB
Dayton, OH 45433

Air Force Flight Dynamics Laboratory
Wright-Patterson AFB
Dayton, OH 45433

Air Force Human Resources Laboratory
Wright-Patterson AFB
Dayton, OH 45433

Air Force Office of Scientific Research
Building 410
Bolling AFB
Washington, DC 20332

Air Force School of Aerospace Medicine
Aerospace Research Branch
Crew Technology Division
ATTN: Dr. Sam Schiflett
Brooks AFB
San Antonio, TX 78235

Air Force Systems Command
Director of Laboratories
Andrews AFB
Washington, DC 20334

Airline Pilots Association
Washington, DC

Army Aeromedical Research Laboratory
Box 577
Ft. Rucker, AL 36362

Army Aviation Research and Development Command
P.O. Box 209
St. Louis, MO 63166

Army Research Institute for Behavorial and Social Sciences
Room 6N12
5001 Eisenhower Avenue
Alexandria, VA 22333

Army Research and Technology Laboratory
DAVDL-AS
207-5 Ames Research Center
Moffett Field, CA 94035

Defense Advanced Research Projects Agency
1400 Wilson Boulevard
Arlington, VA 22209

Department of Transportation
Federal Aviation Administration
800 Independence Avenue
Washington, DC 20591

Department of Transportation
Research and Special Programs Administration
Washington, DC 20590

Federal Aviation Administration
P.O. Box 25082
Oklahoma City, OK 43125

NASA Ames Research Center
Moffett Field, CA 94035

NASA Langley Research Center
Flight Management Branch
Hampton, VA 23669

National Institute of Mental Health
Bethesda, MD

Naval Aerospace Medical Research Laboratory
12475 Airblac Drive
Pensacola, FL 32506

Naval Air Development Center
Crew Systems Branch
Warminster, PA 18974

Naval Air Test Center
Patuxent River, MD 20670

Naval Air Systems Command
AIR-340F
Washington, DC 20705

Naval Biodynamics Laboratory
Box 29407
New Orleans, LA 70189

Naval Health Research Center
San Diego, CA 92152

Naval Medical R&D Command
Bethesda, MD 20014

Naval Personnel Research and Development Center
San Diego, CA 92152

Naval Sea Systems Command
Washington, DC 20362

Office of Naval Research
800 North Quincy Street
Arlington, VA 22217

Pacific Missile Test Center
Point Magu, CA 93042

FRANCE

North Atlantic Treaty Organization
Advisory Group for Aerospace Research and Development (AGARD)
7 Rue Ancelle 92200
Neuilly Sur Seine

GREAT BRITAIN

European Office of Aerospace Research and Development
223/231 Old Marylebone Road
London NW1 54

Science Research Council

Social Science Research Council

Medical Research Council

U.K. Ministry of Defense

U.K. Department of Energy

Department of Employment

WEST GERMANY

Bundesministerium fur Forschung and Technologie
(Mo Research/Technology)
D-5300
Federal Republic of Germany

Bundesministerium der Verteidigung (Mo D)
Psychologis Cher Dienst
Referat PII4
Postfach 1328
D-5300 Bonn
Federal Republic of Germany

Deutshe Forschungsgemeinschaft (DFG)
(German Research Society)
Postfach 20 50 04
Kennedyallee 40
D-5300 Bonn 2
Federal Republic of Germany

CANADA

National Science and Engineering Research Council

Transport Development Corporation

NETHERLANDS

Ministry of Public Health and Environmental Affairs

ZWO Netherlands Organization for Pure Scientific Research
The Hague Ministry of Social Affairs

Section 7

SIGNIFICANT PUBLICATIONS IN MENTAL WORKLOAD

This section is a bibliography compiled from responses to a request to list those journal articles, books, reports, and conference proceedings which, in the opinion of the researcher, have made the greatest contributions to the understanding of mental workload.

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